G. L. Simmons

THE

PRINCIPLES

OF

ANIMAL AND VEGETABLE PHYSIOLOGY:

A POPULAR TREATISE

ON THE

FUNCTIONS AND PHENOMENA OF ORGANIC LIFE.

TO WHICH IS PREFIXED

A GENERAL VIEW OF THE GREAT DEPARTMENTS

OF

HUMAN KNOWLEDGE.

BY

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WITH ONE HUNDRED AND TWO ILLUSTRATIONS ON WOOD.

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PUBLISHERS' ADVERTISEMENT.

THE present volume has just been issued in London as one of a series of Treatises published under the general title of "Orr's Circle of the Sciences." The editor of the series, and author of this volume, is DR. BUSHNAN, whose name, in connection with those of OWEN, ANSTED, LATHAM, and other contributors to the enterprise, carries with it the guarantee that however simple the work may be in form and popular in style, yet that its facts are strictly in accordance with the latest scientific investigations, and that nothing has been omitted which should find place in a manual destined for the general reader or the academical student.

The views which have actuated the author may be found in the following extracts from the English Preface:

"In the Introductory Treatise to this Volume, an attempt has been made to expound, in brief and lucid terms, the general nature, relations, and applications of all the chief departments of Human Knowledge, in order to give the Reader, not specially trained in Science, a general view of the vast field of inquiry which the Creator has laid open to the lawful exercise of the human intellect. Thus the Student has been led, in the first instance, and it is hoped by no rugged or precipitous ascent, to the summit of an eminence

whence he may take a survey of the various departments of knowledge, and of the principles which ought to guide him in the pursuit and application of the several Sciences.

"In the Treatise on the Physiology of Animal and Vegetable Life, the duties or functions of the organs in the living bodies of plants and animals are defined and classified; and the results of a complete analysis of the constituents of these organs are given, after they have been reduced by the anatomist to their component textures, and by the chemist to their proximate and ultimate elements. The principal modifications of the functions are traced through the different classes of animals, and the leading phenomena of the development of the germ and embryo, in both the divisions of the organic world, are described. The endeavour of the Author has been to compress into the compass assigned to each essay an outline of the chief characteristics of life in the two great departments of Organic Nature, a statement of the relations of Plants and Animals to each other, and an account of their common dependence on the mineral or inorganic world."

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ON THE

NATURE, CONNEXIONS, AND USES

OF THE GREAT

DEPARTMENTS OF HUMAN KNOWLEDGE.

BEFORE man became a philosopher he was a discoverer; and in his capacity for discovery, and for reasoning on its results, he differs widely from all other beings. In the organic world there is no history but the history of man. The doings of one pair, or of one colony of inferior animals, however sagacious, are the doings of generation after generation. Birds build their nests in our gardens and shrubberies as they built their nests in Eden; the bees in our hives construct their honeycomb, as the bees of Samson's time did that which he took from the lion's carcase; and the beavers of Canada rear their dams, and huts, and burrows at this day as they have done ever since their species was created. How different is the account of man's proceedings from the time of his first appearance upon the earth! What variety in his modes of clothing himself—of building habitations—of defending himself from beasts of prey—of transporting himself from place to place—of subjecting to his power the animate and the inanimate Creation!

In the first advances made by primitive man, his capacity for the attainment of knowledge shines forth almost as vividly as in the discoveries made during his most advanced state of civilization. To draw a distinction between the faculties of man and the faculties of the highest among the animal creation has always been a task of much difficulty; and yet how frivolous appear the attempts to trace a proximity between endowments but outwardly similar, the moment the actual fruits of man's faculties are contrasted with the nothingness of effect produced by any other species on the surface of the earth! It can hardly indeed be said with truth that man's mere

senses are more perfect than those of the animals which stand near him in the scale of being; but it is an obvious truth that he has a capacity to originate ideas which mould the observations of sense on a higher and more perfect type.

In man's early progress, the rudiments of almost every branch of knowledge may readily be traced. His intellectual pre-eminence in the animal kingdom may be reduced to a few prominent heads—namely, to his great capacity, in the first place, for appreciating the abstract relations of number and quantity; secondly, to his exact perception of the resemblances and the differences of objects of sense; thirdly, to his inherent disposition to form objects and appearances, which agree even in one quality or mode of presenting themselves, into groups—which are afterwards to be recognised as possessed of a unity of character; fourthly, to his complete feeling of the distinctness of his bodily self from the rest of nature; to his instant perception of its slightest change of position or attitude; and, to his almost unlimited voluntary power over its movements, so that it becomes an exact measure of the numerous relative properties of surrounding bodies; and, lastly, to his capacity for looking inwards upon himself, and taking note of the special effects produced on his internal nature by persons, and things, and circumstances. With these several heads the great departments of human knowledge, as we shall discover, intimately connect themselves.

Science.—The systems of knowledge founded on intuitive convictions of the human mind, to which the name of science is currently given, are, in particular, the Abstract or Mathematical Sciences. Those collected from the perceptions of sense, with or without the aid of instruments and of the abstract sciences, and methodised by man's faculty of grouping individual appearances into compound unities, are the Inductive Sciences, under which falls the chief part of physical knowledge—namely, several branches of Natural Philosophy, the whole of the Electrical Sciences, Chemistry, and some parts of Physiology. Those founded in the same manner upon the organic kingdoms of nature, with the aid of certain fundamental intuitive convictions of the human mind, constitute the Physiological sciences. Those directly deduced from man's contemplation of the subjects of his consciousness, and the report of others as to the results of their reflections on what consciousness has taught them, make up the Psychological sciences, Metaphysics, Ethics, &c. Those drawn from the contemplation of man in his social state, as bearing on the welfare of the community, are represented chiefly by Statistics and Political Economy. Those which rest on moral evidence, in its three degrees of possibility, probability, and moral certainty, rather than on the evidence of sense, are Government, Law, Medicine, Taste, Criticism, &c. Those which are formed by comparing the

substances composing the exterior of our planet, and the individuals of the animal and vegetable kingdoms, and by marking their resemblances and differences, constitute the Natural History of the three Kingdoms of Nature. And lastly, the systems of knowledge derived from the observation of the minute structure of minerals, plants, and animals, and the grouping of certain frequently recurring resemblances into separate unities, each denoted by a single expression, constitute what have been termed the Descriptive Sciences, such as Zootomy, or Anatomy commonly so called, Phytotomy or Vegetable Anatomy, and Crystallography.

Such, then, is an enumeration of the great branches of human knowledge, of which it is our intention in the present undertaking to treat. But, at present, let us examine more narrowly the resemblances and differences of the evidence on which these several branches of knowledge depend, and endeavour to ascertain their connections and the precise uses to which each is subservient.

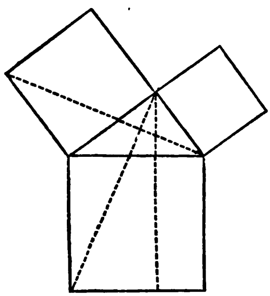
We will premise, however, that although the name of science is currently applied to the more profound parts of man's studies, the term has no definite signification. In particular, it is employed indiscriminately to denote those systems of knowledge which are deduced from the inherent or intuitive convictions of the human mind, as well as those systems of knowledge which are built upon the perceptions of sense, variously grouped into a whole, because of the agreement of the members of each group in one mode of presenting themselves. But vague as is the term science, it is too firmly rooted to be rejected.

Geometry. — When any part of Mathematics, for example, Geometry, is compared with some one of the Inductive Sciences, such as Chemistry, it is discovered how loosely the term science must be used to apply equally to both. For this purpose, we select for contrast the properties of the alkalies, on the one hand, and on the other the remarkable property of the right-angled triangle, that the square of its hypotenuse is equivalent to the sum of the squares of the two sides. The alkalies — that is, the pure caustic alkalies — are freely soluble in water and in alcohol; each saturates its own proportion of every known acid; and were a new acid discovered, it would only be necessary to ascertain how much of it is required to saturate a given quantity of one of the alkalies, to pronounce how much of each of the others that same quantity would saturate; the alkalies, besides, form soaps with oils; they change vegetable blue colours to green, and yellows to brown. By means of these properties, the chemist is able to detect the presence of any pure alkali in his analysis; and such is one of the great objects which the science of Chemistry has in view. But the point which we wish chiefly to be

borne in mind is, that from the whole history of Chemistry no reason can be elicited why an alkali should be soluble in water rather than insoluble, or soluble in alcohol rather than insoluble; why it should combine with oils or acids rather than resist combination with them; why it should change vegetable blues to green, and yellows to brown, rather than to any other colour. In the conception of properties, as belonging to the alkalies, opposed to all those just enumerated, there is nothing contradictory. In short, there is no reason why any peculiar property of an alkali, so far as the human faculties can comprehend, should not, in the arrangement of nature, have been the opposite of what it actually is. And the same may be said of all those laws and properties in nature which are discovered solely by observation.

On the contrary, when the several steps are considered by which an equality is proved between the square of the hypotenuse in a right-angled triangle, and the sum of the squares on its two sides, there is not discoverable, in the whole course of the demonstration, any single truth, the opposite of which does not involve a contradiction, so that, independently of any observation, the human mind is, by its very nature and constitution, compelled to extend to them an absolute and unconditional belief.

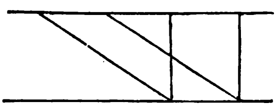
FIG. 1.



The square described on the hypotenuse being cut by a straight line in such manner as divides it into two distinct parallelograms, it is at once shown by the undeniable proposition, that if two equals have each an equal quantity added to them, the sums are equal; and then by the undeniable proposition that the doubles of equals are equal to one another — that each of the two divisions of the square on the hypotenuse is equal to one of the squares on the two sides of the triangle.

The proof of the theorem just referred to, may readily be understood even by one unversed in the elements of geometry. With the meaning of parallel lines every one is familiar. Here are three pairs of parallel lines; one pair running from side to side, and two pairs between them, forming two parallelograms of rectilinear figures, the opposite sides of which are parallel. These two parallelograms stand upon the same base, and lie between the same parallels; and when this is the case parallelograms are equal — that is, the area of the more

FIG. 2.



upright of these two figures is equal to the area of the more slanting figure. And the truth of this will appear at once, by considering how the whole figure, composed of the two parallelograms taken together, is made up. If from this whole figure the more upright of the two parallelograms be taken, a triangle remains; and if from the whole figure the more oblique parallelogram be taken, another triangle remains. But these two triangles are equal, their corresponding sides and angles being equal; hence the parallelogram which remains, after one of these triangles is taken away, must be equal to the parallelogram which remains after the other triangle is taken away. Such, then, is the proof of the proposition, that parallelograms between the same parallels, and standing on the same or an equal base, are of the same area; and as every parallelogram is divisible into two equal triangles by its diagonal, it follows that triangles standing on the same base, and between the same parallels, are of the same area.

Let us now return to the figure on the preceding page, representing the squares on the three sides of a right-angled triangle. In this figure there is a triangle standing on the same base, and between the same parallels as the square on the left-hand side of the triangle, and there is a triangle standing on the same base, and between the same parallels as the larger of the two parallelograms into which the square of the hypotenuse is divided; but these two triangles are equal, owing to the equality of two sides, and the contained angle; hence the square, which is equal to twice the area of one of these equal triangles, is equal to the parallelogram, which is equal to twice the area of the other triangle. And by the same mode of reasoning, the square on the right-hand side of the triangle is proved to be equal to the lesser of the two parallelograms into which the square of the hypotenuse has been divided.

But in the whole range of Geometry the proposition holds good, that every stage of the proof is a truth, the opposite of which involves a contradiction; and therefore, that it is itself a necessary article of belief. In short, it is incontrovertible that mathematical truths are necessary truths. Geometricians use various ways of convincing us of this: where two figures are necessarily equal, as a consequence of certain parts in one being known to be equal to corresponding parts in the other, the method of superposition is frequently employed; that is, we are required to fancy one figure placed upon the other, and then, mentally, to bring about their perfect adaptation: the parts, previously known to be the same in both, being properly adjusted, the other parts, by this method, are shown to be necessarily coincident. There is, however, nothing of a mechanical or experimental character in this process: the figures are not bodily transported from one place to another; the whole is a

purely mental operation; and it is the mind, not the eye, that sees the complete adaptation of the two.

Some superficial thinkers cavil at the peculiar character assigned to mathematical science, by reference to the very proposition above adduced; saying that the fact as to the equality of the squares, was discovered by observation, and the demonstration afterwards invented; as is proved, they further say, by the tradition, that Pythagoras sacrificed a hecatomb in gratitude to the gods, for having inspired him with its discovery. Thence, it may be supposed, they would infer, that all mathematical knowledge is founded on observation, and not on intuitive convictions of the human mind.

It is evident, however, that many truths, susceptible of a mathematical demonstration, like that respecting the squares on the sides of a right-angled triangle, are discoverable by observation; and doubtless, in the early progress of geometry, this method was much employed to discover the course to be adopted for the extension of this branch of knowledge. But had geometry, or any other part of mathematics, been confined to this method of investigation, would it ever have attained the rank of being the handmaid of inductive science—the very means by which observation has been made capable of deciphering the system of the universe?

The distinction between mathematical truth and inductive science, so clearly pointed out by the contrast between the properties of the alkalies, and the remarkable properties of the right-angled triangle above referred to, is irrefutable.

Magnitude.—We have not hitherto referred to the great object which mathematical science has in view, namely, to supply a measure by which all magnitudes may be rendered commensurable. A few words will give the steps by which this is accomplished in a sufficiently clear light.

By the propositions readily reducible to the truth, before referred to, that two triangles are equal, if their corresponding angles and corresponding sides be equal, any two rectilineal figures, however dissimilar, may be proved to be equal if they really be equal, or unequal if they be unequal. And this may be described as the first great step in Mathematical Science; because, by means of the equivalence of triangles, all rectilineal figures are rendered commensurable.

The next step in Mathematics is to find the measure of figures bounded by curved lines. For example, to find the area of a circle in rectilineal measure.

The attempts to find the area of a circle in rectilineal measure gave rise to the proof by the method of "exhaustions," as it is termed.

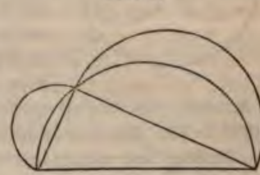
The area of a circle is a quantity intermediate between the area of a polygon circumscribing the circle, and that of a similar polygon inscribed within the circle. If the number of sides in each of these polygons be successively increased, the area of the interior polygon is continually augmented, while the area of the exterior polygon is continually diminished, — plainly, however, on this condition, that though the area of each continually approaches nearer and nearer to the area of the circle, that of the exterior polygon can never fall short of the area of the circle, nor that of the interior polygon exceed the area of the circle. Thus, as the sides of these polygons may be increased without any limit, the difference between the area of the exterior polygon and the area of the interior polygon is continually becoming less and less, or continually approaching, without reaching, to nothing; and though the rectilineal polygon cannot be made an exact measure of the curvilineal circle, yet it can be made to approach to its measure with any required degree of nearness. It may be remarked here, also, that this operation enables the unlearned reader to understand what is meant when it is said that unity divided infinitely $= 0$.

FIG. 3

It was another step in Mathematics when the area of curvilineal figures came to be expressed exactly by the areas of rectilineal figures. What are called the "lunes" of Hippocrates, known to the ancients, afforded one of the earliest examples of this coincidence. To exhibit this property, a right-angled triangle is inscribed in a semicircle, and a semicircle described on its base and its perpendicular. The portions of the two last semicircles which lie without the original semicircle, are found to be equal to the area of the triangle.

The following is the kind of proof on which this proposition rests. It is found that if semicircles are described on the three sides of a right-angled triangle, the area of that described on the hypotenuse is equal to the joint areas of the semicircle on the base and that on the perpendicular. But the greater semicircle in the annexed figure consists of the right-angled triangle and the two arches of that semicircle cut off by the sides of the triangle, and the joint areas of the two lesser semicircles consist of the two lunar spaces cut off by the greater semicircle and the two arches of that great semi-

FIG. 4.

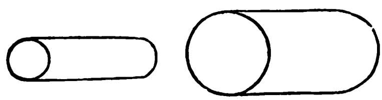


circle just mentioned; hence, if from each of these two equal quantities, the common quantity in both, namely, the arches of the great semicircle cut off by the sides of the triangle, be taken away, there remains on the one hand the triangle, and on the other the lunar spaces of the lesser semicircles, taken together, equal to each other.

The propositions, on which the proof of this correspondence in equality depend, are easily understood.

The circumference of a circle is proportional to its diameter — a proposition which may easily be shown to be a necessary consequence of the geometrical definition of proportion. It is not, however, so obvious that the area of one circle is to the area of another circle, as the square of the diameter of the first circle to the square of the diameter of the second circle.

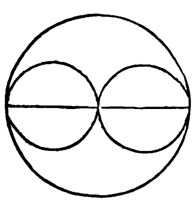
FIG. 5.



It is, however, a very important proposition, for, if a person supposed that the areas of circles are simply proportionate to their diameters, he might commit many serious errors. For example, if he wished a tube, as a gas-tube, twice the capacity of another tube, and desired it to be made of equal length, but twice the diameter, it would turn out to have four times the capacity; for the square of a line eight inches long consists of sixty-four square inches, while that of a line four inches long consists of only sixteen square inches.

That the areas of circles are not to one another as their diameters, is a truth of which the learner may easily satisfy himself without any knowledge of Geometry; thus: let a circle be described with any diameter, and within it let two circles be described, with the diameter of each only half that of the outer circle; then if a circle, with double the diameter of another, were no more than double that of the other in area or surface, it is plain that the two inner circles would just fill up the outer, which is at once seen to be impossible.

FIG. 6.



It is, however, worthy of remark, that the circumference of the outer circle would be exactly equal to the two circumferences of the inner circles, which is only one among the many interesting and unexpected truths that Geometry presents.

But the great progress made in this part of Mathematics has arisen from the investigation of the areas produced by the higher order of curves, as of the conic sections, exemplified in the ancient

discovery that a parabola is equal to two-thirds of its circumscribing parallelogram.

But it would be superfluous to carry these illustrations further, since it already sufficiently appears what is the proper object of Mathematics, and that the evidence employed in this Science uniformly consists of propositions, the reverse of which, according to the constitution of the human mind, involves a contradiction.

Number. — Our observations have been confined hitherto to what relates to magnitude; but the doctrine of number is in no respect different. That 2 and 2 make 4, and that 2 taken from 4 leave 2, are unquestionably intuitive truths — they must be believed; they are necessary truths, because the opposite propositions involve a contradiction. But the truth that 10 times 10 make 100, rests on the same kind of evidence. One repeated a hundred times makes 100. Observation is not required to prove 10 times 10 to be 100; it is merely required to discover if what is called 100 be 100. If, in the primitive state of our race, one man, on giving another figs or dates, held up the fingers of both hands ten times, he who received them would count them, not to ascertain if 10 times 10 were 100, but to discover if he who gave the fruit had spoken truly as to the number.

Mathematical Evidence. — All Arithmetic, then, rests on the same evidence — all its truths are necessary; and the same may be said of Algebra, Logarithms, and the Differential Calculus. Algebra may be described as Arithmetic carried on by symbols; so that the kind of operation is constantly indicated, but not actually performed till the relation between the given quantities and the quantity sought, be reduced to its simplest possible form. Logarithms depend on what seems a singular property of numbers; yet that property is as certainly deducible from necessary truths as any truth in Mathematics. If two series of numbers stand respectively in Geometrical and Arithmetical ratio, it is found that the product of any two numbers in the Geometrical series may be found by adding the corresponding numbers in the Arithmetical series, and then taking the number in the Geometrical series which stands opposite: and this is the product sought.

Logarithms. — The most difficult and complicated arithmetical operations may be performed with ease and expedition by means of Logarithmic tables; and thus multiplication is reduced to addition, division to subtraction, evolution to multiplication, and the troublesome process of involution, or the extraction of roots, to simple division. Astronomy owes much of its pre-eminence, as an exact science, to the discovery of Logarithms, as, without their aid, it would have been almost impossible to have made the calculations necessary to confirm its laws. The astronomer reduces his algebrai-

cal formulæ to a form adapted for logarithmic computation; and his assistants, by the simplest rules of arithmetic, are thus enabled to compile the Nautical Almanac, without which the commerce of our great nation would be nearly destroyed — the Nautical Almanac and a table of logarithms being as essential to the mariner as his chart and compass.

Proportion. — To exhibit a tithe of the uses to which the sciences of quantity and number can be applied, would fill a volume. Still the only practical use of these important sciences, is the measurement of quantities before unknown. The great instrument in all the departments of abstract science is proportion; thoroughly to understand which is to possess an instrument of knowledge applicable to almost every situation in life. When Thales of Miletus travelled into Egypt, 600 years before Christ, and saw the Great Pyramid, he

Fig. 7.

was curious to determine its height, which hitherto it had been deemed impossible to ascertain. Observing the shadow of the pyramid as the sun shone upon it, stretching far in the opposite direction, he struck his staff upright in the sand; and finding the shadow which it cast to be exactly its own length, he rightly concluded that the shadow, measured from the middle of the base of the pyramid, must equal in length the height of the pyramid. He paced the shadow, and found its length to be 270 paces, or about 500 English feet. Pliny, who relates this anecdote (lib. xxxvi. 17), expressly says that Thales measured the shorter shadow at the time when it was of the same length as the staff.

But although equality in length of the shadow and the body may be allowed to be necessary for the discovery of this mode of mensu-

ration, it would quickly appear without any necessity for experiment, that whatever relation the shadow bore to the staff, the same relation of magnitude would the shadow bear to the height of the pyramid. The three things requisite are, the measure of the shadow of the staff, the measure of the shadow of the pyramid, and the measure of the staff itself. But, to solve this more complex problem, the knowledge of proportion is necessary: namely, that when of four numbers the first two bear the same analogy to each other as the last two to each other, the first of the four, multiplied by the last of the four, is equal to the second multiplied by the third; or, as it is usually expressed, the product of the extremes is equal to the product of the means:—or 4 : 16 :: 20 : 80—that is, 4 is to 16, as 20 to 80; but the product of the extremes, 4 and 80, is 320; and the product of the means, or middle numbers, 16 and 20, is also 320. But when three numbers are known, and a fourth is sought in the same relation to the third which the second holds to the first, it is plain that the product of the means can be obtained, and that that product being also the product of the extremes when both these come to be known, and being divided by the first extreme, the second extreme will be obtained: that is, if in the above formula 16 and 20 be multiplied together, and the product divided by 4, the fourth number, the second of the two extremes, or 80, will be obtained.

And this rule of proportion prevails throughout the whole range of the sciences of magnitude and number. In every kind of measurement proportion plays its part, with the exception of that which is of the rudest kind. In the measurement of the height of the

Fig. 8.

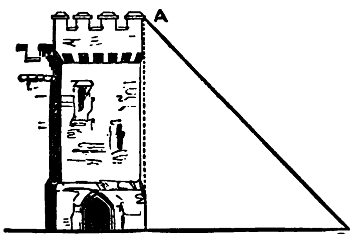
Great Pyramid by Thales, the idea of proportion is involved, although hardly brought out into relief. We will cite another example of the measurement of a height without distinct reference to proportion. The height of a tower or pillar—no matter how high—which

stands on a level plain, and the foot of which is accessible, can be measured as soon as men have discovered that in a right-angled triangle, the sides of which are equal, each of the other two angles is equal to half a right angle, and the perpendicular equal to half the hypotenuse. If the perpendicular line in a right-angled triangle represent a tower, it is evident that its height is equal to half the hypotenuse, or side opposite to the right angle at A. Thus, if a person setting out from the foot of the tower pace the distance to the point at which the top of the tower is seen at an elevation of 45°, or half a right angle, the number of paces he has taken indicates the height of the tower.

Trigonometry. — The usual mode of determining heights is by the rules of Trigonometry, without any necessity for the angle of elevation being of a particular number of degrees.

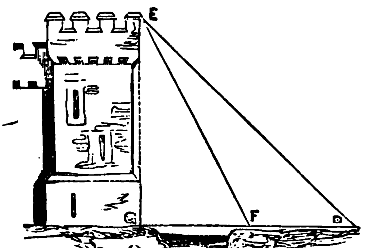
When a tower is accessible, the angle B C A is measured, and the base of the triangle C B; the angle at B is known, being a right angle, and the angle at A is found by subtracting the angle at C from 90° or a right angle; because since the three angles of every triangle are together equal to two right angles, the angles at C and A are together equal to one right angle.

Fig. 9.



When the foot of the tower is inaccessible, the angle G F E is measured, then the space F D and the angle F D E; the angle E F D is found by subtracting G F E from two right angles, since every straight line falling on another straight line forms with it two angles, together equal to two right angles. But when the angles D and F in the triangle E D F are known, the angle at E is easily found by subtracting the sum of the angles D and F from two right angles. But as a general rule in Trigonometry, when out of the three sides and three angles of a triangle, any three, except the three angles, being given, the remaining three can be determined. Hence the length of the line A B in the triangle A C B, or the height of the tower, can be so dis-

Fig. 10.



covered; and in the triangle FDE the length of EF can be discovered, as preliminary to the same steps.

Motion. — The laws of motion, which make up so important a part of Natural Philosophy, stand at once on a different footing from mathematical truth, and from the principle of gravitation. It is common to enumerate three laws of motion. The first is, that a body under the action of no external force will remain at rest, or move uniformly in a straight line. The second, that when a force acts upon a body in motion, the change of motion in magnitude and direction is the same as if the force acted upon the body at rest. The third law of motion is, that when pressure communicates motion to a body, the momentum generated in a given short time is proportional to the pressure, or, as given by Newton in a more general form, action and reaction are equal and opposite.

In order to form a correct notion of these laws, we must have definite ideas of bulk, force, velocity, motion, and pressure, as well as the modes of measuring them. Newton defines the mass of a body to be the product of its density and its volume; and he determines the mass by its weight, because he found, by most accurate experiments with pendulums, that the mass is proportional to the weight. We see that all bodies placed above the earth's surface have a tendency to fall, and exert a force upon whatever support prevents them from falling; this force we term pressure, and the measure of this pressure is weight—bodies being said to be of equal weight, if they produce equal pressure on their support; consequently weight is a measure of the earth's attraction for heavy bodies; but, in assuming weight to be a measure of mass, or the quantity of matter contained in a body of given volume, we clearly assume that the earth's attraction is the same for all kinds of matter; and that a cubic inch of gold weighs more than a cubic inch of copper, because the former contains more particles of matter than the latter, and not because the earth has a more powerful attraction for gold than copper — an assumption abundantly confirmed by experiment. Hence weight becomes a measure of pressure, and consequently of force producing pressure. We can also estimate force, in another way, without reference to mass, pressure, or weight. According to the first law of motion, a body can only move by the action of some external force; now, the space through which it passes in a given time will afford us a measure of its velocity, which is only a term for the quickness or slowness of its motion; and the velocity acquired in any given time will afford us a measure of the force which produces the motion of the body. Neglecting the resistance of the air, it is found that all heavy bodies, how different soever in weight, fall through the same space, and acquire the same velocity at the end of any given interval of time. It is clear, therefore, that the measure

of a force, by the velocity it generates in a given time, in no way involves any consideration of the mass, and must therefore differ from our previous measure of force.

Force, measured by the velocity generated in a given time, is called accelerating force; force, measured by weight or pressure, is termed moving force. Now, though we can conceive, as a consequence of what we have said, that two equal accelerating forces, acting separately on two different masses, would cause them to acquire the same velocity, at the end of a given time, it does not follow that these different bodies would produce the same effect on any body which might oppose their motion. In order that they should do so, it is necessary that the product of the mass and the acquired velocity, should be the same for both moving bodies. Thus a ball of 2 lb. weight, moving with a velocity of 50 feet per second, will cause a ballistic pendulum, when struck by it, to vibrate through the same arc as when struck by a ball of 50 lb. weight, with a velocity of 2 feet per second, or a ball of 100 lb. with a velocity of 1 foot per second. The product of a body's mass, and its velocity, is called its momentum, or quantity of motion.

If we conceive two equal weights, W and W′, suspended from the extremities of a string passing over a pully P, supposed to be destitute of friction, the weights will remain at rest. If we place ever so small a weight, x, on the weight W, the weight on which we place it must immediately descend; and, as long as x is placed on W, by the first law of motion, the velocity of its descent will continually increase. If we remove x the weight W will still descend, but with the velocity constant, which it had acquired at the instant of x's removal. Now in this case the weight x is called the moving force, or pressure producing motion; the two weights W and W′, together with x, the mass moved: the velocity of W's motion will be a measure of the accelerating force produced by x. Now it is found, by numerous careful experiments, that this accelerating force, multiplied by the mass moved, $2W+x$, is always proportional to the pressure-producing motion x: and this is the third law of motion.

FIG. 11.

The laws of motion cannot be proved by any series of experiments, however extensive — these experiments only suggest the laws; and perhaps our firmest conviction of their truth arises from the wonderful manner in which, by combining these laws with the principle of gravitation, Astronomers have been able to predict the motions of the heavenly bodies with such marvellous exactness, and even to point out with certainty the precise spot in the heavens

where a planet hitherto unknown would be found. To some minds these laws may appear objects of intuitive belief, when once we have acquired correct ideas of matter, force, and motion; but on this point some metaphysical difficulties clearly exist. Our natural belief in the laws of motion certainly differs from that which prevails in regard to mathematical truths; for the opposite of mathematical truths at once presents a contradiction, while the opposite of the laws of motion may not exhibit itself at first as a contradiction to every mind.

Moreover the human mind cannot conceive that even Omnipotence can make two and two anything but four. Nevertheless, if we contemplate a heavenly body at perfect rest, on the assumption that it is for the time the only body in space, that heavenly body, in the language of the first law of motion, will remain at rest for ever, unless some cause of motion come into operation.

In this case who will dare to say that it is impossible for Omnipotence to move that heavenly body without applying a cause of motion? Such an assertion would be wholly inadmissible, unless, among the causes of motion, it is understood that the Fiat of the Almighty is included.

The Balance. — The principle of the Balance seems at first sight self-evident; for it is self-evident — at least to a person of ordinary

FIG. 12.

FIG. 13.

intelligence — that if a rod of uniform material and dimension be fixed by its middle point on a pivot, and two bodies equal in weight be suspended one from either extremity, they will be in equilibrium. But to render this proposition intelligible, the nature of gravity, as a property of bodies at the earth's surface, must be clearly seen.

That being understood, the proposition will then stand thus: — Equal causes, applied exactly in the same manner, must produce equal effects; the causes being the like number of particles tending downwards on either side of the fulcrum. And, by an easy de-

monstration referable to self-evident principles, it can be shown that when the weights differ, there is, nevertheless, an equilibrium, if the fulcrum be at the point in the rod which divides it inversely in the ratio of the weights.

This case, however, plainly differs from the convictions afforded by the necessary truths of mathematics, since the reasoning is mixed up with principles ascertained by experience, — the gravity of bodies, for example. And the same thing may be said of the demonstrations respecting the mechanical powers in general, — the lever, the wheel and axle, the pulley, the inclined plane, the wedge, and the screw.

In Hydrostatics it is self-evident that a solid and insoluble body, immersed in a liquid, must displace a quantity of the liquid equal to its bulk. The discovery of this fact cost Archimedes a great effort; but the moment it occurred to his mind, it was self-evident, and required no proof to obtain universal assent. That a solid floating body, like a ship of the line, displaces a quantity of water equal to its weight, is equally true, but not, at first sight, quite so obvious.

The refraction of light, to which so many phenomena can be referred, admits of no explanation. The evidence of the truth of this law is as yet derived solely from observation; and a wholly opposite condition of the law could be as readily received upon the same evidence as its actual form.

Gravitation. — The law of Universal Gravitation rests ultimately on observation. It is the greatest achievement of Inductive Science. It is expressed in the language of Mathematics; but it has nothing of the character of a mathematical truth. This law declares the mutual gravitation of all bodies, with forces directly as their quantities of matter, and inversely as the squares of their distances.

In the expression of this law bodies are conceived to consist of minute particles, more or less closely aggregated or packed together. In Physics, all such component particles of matter (differing from the laws on Chemistry) are regarded as made up of the same small portions of matter; that is to say, it is a part of the law that any two particles, at whatever distance from each other, exert the same mutual attraction. Thus the attraction of one body or mass of matter for another if the sum of the attractions of all the particles of the one towards the sum of all the particles in the other; and if the attraction be equal on both sides, that is, if the attraction exerted by the one be as great as the attraction by the other, it is determined in the abstract, that the number of particles in the one is exactly the same as the number of particles in the other. But these two bodies, which are thus conceived to contain equal quan-

tities of matter, may be either of the same magnitude, or may considerably differ in magnitude. A cubic foot (that is 1728 cubic inches of water,) contains no more matter than 128 cubic inches of mercury, which is the same thing as to say there is the same number of particles of matter in 128 cubic inches of mercury as in 1728 cubic inches of water.

The law of Gravitation is expressed in its simplest form, as respects particles of this kind — namely, the particles of matter attract each other inversely as the squares of their distances. For example, to make the violent supposition that there is previously no matter in the universe, let two particles of matter be called into existence, and observed first at the distance of five miles, and then at three miles from each other. Their attraction for each other is greater at the distance of three miles than at the distance of five miles; but the greater attraction is not represented by 5 and the less by 3, but by the squares of those numbers, that is, by the one and the other of these numbers mnltiplied each into itself, the products of which multiplication are 25 and 9. Thus the attraction between these two particles at five miles' distance is represented by 9, and at the distance of three miles by 25. The law does not indicate the velocity with which two such particles will approach each other; but did we know what proportion each bore to the whole mass of the earth, then it might be discovered by reference to the velocity of bodies falling near its surface — sixteen feet in the first second.

We may here remark how the laws of motion mix themselves up with the law of gravitation, — the same supposition being continued as to the absence of all other matter in space. If, after these two particles had approached to within three miles of each other, one of them were annihilated, all attraction would of course cease; but the other particle, in accordance with the first law of motion, would continue to move onwards in a straight line with the velocity which it had acquired at the moment of the extinction of the other.

Attraction. — To express the attraction exercised by the particles of the sun over the particles composing each of the planets, numbers must be fixed upon which express, in some kind of dimension, the distances of each of these from the sun, and these numbers being squared we shall obtain a series denoting their relative attractions. To keep down the number of figures, it is best to choose some large measure, for example, the distance of the moon from the earth, or 240,000 miles.

In the following table are set down the squares of the distances of the old planets from the sun, expressed in numbers, denoting how many times each planet is more distant from the sun than the moon is from the earth.

3*

Mercury	25,600	Jupiter	4,410,000
Venus	78,400	Saturn	12,960,000
The Earth	160,000	Uranus	57,760,000
Mars	360,000		

These numbers, however, do not express the actual attraction between the sun and these several planets; but only what their relative attractions would be, if each contained the same number of particles. But where an estimate is already formed of the quantity of matter in any planet, and that quantity is considered in connection with the estimate of the quantity of matter in the sun, and the actual velocity in bodies falling near the surface of the earth, then the elements are afforded for calculating the actual force of gravity between the sun and that planet. The roots corresponding to the numbers in the above table denote the actual distances of the planets from the sun, as measured by the distance of the moon from the earth, — namely, for Mercury, 160; for Venus, 280; for the Earth, 400; for Mars, 600; for Jupiter, 2,100; for Saturn, 3,600; for Uranus, 7,600; or nearly as 1, 2, 3, 4, 15, 28, 54.

It is easy to see that the law of gravitation is sufficiently stated, when made to refer to particles of matter, by simply saying that the particles attract each other inversely as the squares of the distances. For it follows, as a necessary consequence, when a number of particles are collected into one mass, and a less number of particles into another mass, that the sum of the attractions in the one shall be to the sum of the attractions in the other directly as the number of particles in the one is to the number of particles in the other. Again, when two bodies of the same bulk exhibit exactly the same attraction the one for the other, and under the same circumstances, we conclude that the number of particles in each is the same; and this is what is signified when it is said that two bodies have the same density. Moreover it can be proved that the attraction between the centres of two spherical masses of matter is the same as if the whole particles of each mass were collected within their respective central points.

The attraction between two bodies, or masses of particles, is measured not by the mere velocity acquired by each, but by the amount of motion, or the momentum which each exhibits. When two masses of matter, different in the number of their particles, are supposed to come into existence in free space at some distance from each other, the quantity of motion produced in each is the same. That which contains the greatest number of particles would move with less velocity; that which contains the less number of particles with greater velocity; but the momentum, or quantity of motion, in each will be the same.

It is easy, then, to understand, on the principle of gravitation, why two bodies — for example, a pillow and a piece of lead equal to the pillow in weight — were there no atmosphere, would fall to the

ground from a given height in the same time. Both would have the same momentum: but the momentum or impulse of the piece of lead would be impressed on a small portion of the surface, while that of the pillow would extend over a large surface, so that each point of that surface would be less affected.

At first consideration, it may be somewhat difficult to see clearly that this great law of gravitation essentially differs from a mathematical proposition, as resting not on intuitive convictions but on observed facts. But a closer view of the whole subject satisfies the inquirer that no law of this kind could have been predicted *à priori;* that is, from any natural or intuitive conviction of the human mind. Such knowledge has no other foundation than observation. What confuses the mind is the large extent to which mathematical investigation is employed for the assistance and perfection of observation. Here, however, mathematical investigation serves merely the office of an instrument, by which, indeed, the dominion of the senses over nature is almost immeasurably increased.

Physics. — The several subjects just noticed fall strictly under the head of Natural Philosophy or Physical Science, and indeed merely afford examples for the kind of knowledge which belongs to that great department. But when we consider that Natural Philosophy is ancillary to the great objects of Mechanical Science — to the construction of Time-keepers, the Hydraulic Press, the Steam Engine, Artesian Wells, Gunnery, the Pendulum, Telescopes, Microscopes, the Barometer, the Tides, Railways, &c. — we shall be able to estimate the vast importance of a knowledge of its various subdivisions to men, particularly to those living in countries newly settled, and where the division of labour has not yet been carried sufficiently far to save every man from the necessity of being his own engineer and overseer. Even in the long-established social communities of modern Europe, we have but to glance the eye over the career of individuals of great activity of mind rather than of solid education, to discover how much time and money are annually wasted in the vain hope of accomplishing what is unattainable. Many a man of genius in former times, unenlightened by the knowledge this work is intended to convey, has wasted his life and fortune in fruitless efforts to discover the perpetual motion. And although this is not often now the object to which uninstructed ingenuity is directed, there is still as much health, as much genius, as much industry, as much wealth consumed on things unattainable as in former ages.

Electric Sciences. — The fact that amber, after being rubbed upon woollen cloth, first attracts light bodies and then repels them, and upon which the Science of Electricity rests, derives all the evidence of its truth from observation. The same may be said of all the discoveries hitherto made in Electricity. There is no principle in the

whole subject which could have been inferred independently of observation. It is purely a science of induction; and the same remark may be made of Galvanism. It was as impossible to predict, *à priori*, the decomposition of water, and the other surprising effects of Galvanism, by the mere approximation of two metallic plates immersed in an acid solution, as it is to establish, *à priori*, after the effect is witnessed, that it is really due to the apparatus employed. Of Magnetism, what more can be said than that certain facts have been ascertained by observation? And although it is now sufficiently apparent that Electricity, Galvanism, and Magnetism are merely different forms of one more general science, that conclusion has been deduced, not from any *à priori* reasoning, but simply from the accumulation of facts, and the inference of principles from these by the common process of induction.

Under the heads just noticed, together with those of heat and light, how many subjects fall, of surpassing interest and of the most direct use to men in every situation of life! Some years ago, when the number of steam-boat accidents in the United States attracted public attention, an American writer successfully showed that as many persons every year lost their lives by lightning, within the Union, as by the bursting of steam-boilers. Increased knowledge and attention on the part of engineers have very much diminished the annual mortality from steam-boat accidents; and surely it is not too much to expect that the great annual loss of life by lightning may be materially circumscribed by a better acquaintance with the nature of the electric fluid, and the precautions which such a knowledge may suggest for avoiding danger during the violence of a thunderstorm.

Chemistry. — But Chemistry supplies the best example of a purely inductive science; and the progress which Chemistry has already made is sufficient to make known the final composition of the bodies which man sees on every side around him. It teaches that, out of sixty-three simple substances, all these bodies are constituted. It shows him how to obtain each of those simple substances in a state of purity; and, when it is required, it points out how these simple substances are to be converted into such compound bodies as are necessary to the arts and conveniences of life.

In Chemistry there are no original *à priori* rules. There are no facts or laws discoverable by the mere light of thought, independently of experiment and observation. All that the exercise of genius can do in Chemistry is to suggest new paths to be explored. Chemistry, therefore, is a science which enables us to understand both the extent and the limits of the Baconian precepts. It is wholly inductive; and yet the principles which induction has here afforded,

while they are numerous and most available, are, as laws of nature, neither free from exception nor very comprehensive.

It is by the study of the mere properties of substances that chemists have achieved most of their success. The early progress of Chemistry was tardy in the extreme, until gaseous bodies fell under rigid examination; and from that date its progress has been almost incredible. Chemists for ages knew of several sorts of air; but they seem never to have arrived at the idea, that by determining the several peculiar properties of these airs they might be able to distinguish them from each other. Hydrogen gas has been known from time immemorial as an inflammable vapour, which played about the apparatus whenever sulphate of iron was directly made by the addition of dilute sulphuric acid to iron filings. But although its peculiar inflammable character was known, and even its smell in this way of producing it, and also that it did not appear unless a large proportion of water was added to the acid; yet no one thought of seeking the means of identifying it when otherwise produced, until Cavendish noticed its extreme levity.

There was no deficiency of genius or industry among chemists during the period of this slow progress; but with all their solicitude to pursue the precepts of Bacon, they do not appear to have sufficiently felt the necessity of an exact knowledge of the peculiar properties of every substance, and the means of its identification when present in minute quantity. The only efficient aid which chemistry has derived from exact knowledge is the homely aid of the balance. Until recently, chemical operations were too rude to admit of much advantage from the nice determination of the weights of the substances employed in experiments; otherwise, how many difficulties of former times might have been solved without delay!

In the experiment of burning hydrogen gas with oxygen gas, it was remarked, at an early period, that the apparatus became bedewed with moisture. The gases shrank into nothing, and moisture was found upon the apparatus. Yet it was a long time before the conclusion was drawn, that the water was the product of the combustion. The balance would at once have settled this point, by showing that the water produced equalled the sum of the weights of the two gases exploded.

The subjects which Chemistry embraces are so many necessities of man in his social life. A few examples of the departments of art founded on Chemistry will suffice to show how desirable a knowledge of Chemistry is to every man, whatever his occupation in life. Among these stand prominent the extraction of metals from their ores; the subject of artificial light, or the various modes of artificial illumination; the arts of dyeing and bleaching; the substances fit for fuel; the nature of fire-damp and choke-damp in mines; the

artificial production of ammonia, in reference to agriculture; gunpowder; artificial minerals; chemical tests, and the detection of poisons; ventilation, and disinfecting agents; cements; artificial minerals; pigments; metallic alloys; and other subjects which it is needless here to enumerate.

Physiology. — Next in order to Chemistry stand the Physiological Sciences. The discoveries in this science are to a great extent peculiar laws of nature, while many of the phenomena of living bodies are physical, chemical, and electrical. When the muscular fibre shortens itself on the application of a stimulus, it is in obedience to a pure Physiological law. When the impression conveyed from the surface of the body by a reflex nerve is succeeded by an influence transmitted to an organ of motion, it is in obedience to another distinct physiological law.

Certain laws of nature acting together with the laws of motion produce the planetary movements, so strikingly remarkable for symmetry and harmonious union with each other. On the other hand, certain laws of Physiology, in apparent opposition to the laws of physical nature, and to the ordinary laws of Chemistry, produce effects in every way so surprising, as to have engaged the attention of men in all ages, upon the very peculiar nature of the influences by which such effects can be called forth and sustained with an almost unerring uniformity, during the various limited periods to which the existence of individuals in the two organic kingdoms extends.

There is nothing, in the whole character of physiological science, more at variance with the general economy of nature than the limited duration, in each individual, of the phenomena which constitute animal or vegetable existences;—and the complete isolation, throughout its whole existence, of each individual from other portions of the organic world, after the first separation from the parent organism, is another most striking and peculiar feature of physiological science. The innumerable forms which organism assumes, in the varieties of animal and vegetable species, set at nought every possible idea of their source being a mere physical force of development, under the limitation of a few overruling influences. And what is not less remarkable than the characters already stated, is the manifestation, at every step, of the nice accommodation of means to peculiar ends, in the structure and economy of organic bodies, which renders it impossible to seize the mere inductive laws of Physiology, without a perpetual reference to final causes.

If it be said that the animal or plant could not have existed without certain organs adequate to certain ends—and therefore that such contrivances are merely indispensable conditions of existence,—

the answer is, that organic nature is not a necessary part of the economy of the universe; that the material world, without the organic, was complete in itself; and therefore it is to be concluded, because the organic world exists with marks of design, such as characterise the works of man on earth, as distinguished from the works of nature, that in the origin and maintenance of the organic world there is manifested a special intelligence and wisdom, without continual reference to which Physiology will fail to make the progress of which it is susceptible.

The knowledge of Physiology opens up a new field of human thought. In it we trace the wisdom of the Creator, as in Astronomy we discover manifest proofs of his power. Galen said with truth,—"The study of Anatomy is the use of a hymn in praise of the wisdom of God." This is, indeed, the most dignified office of Physiology; and it is in this light that it exhibits its greatest glory. But to how many subordinate uses is it also subservient! Under Physiology, in its largest sense, stand Medicine and Surgery. In proportion as the knowledge of even a rude Physiology has diffused itself has the value of human life increased. Both Medicine and Surgery are but handmaidens of Nature; but how ineffectual — nay rather, how pernicious — were man's natural modes of treating diseases and injuries, until Physiology had enlightened him! One great use of a knowledge of Physiology is to teach men what they should avoid doing when diseases have arisen, or injuries have been sustained. He who understands something of the animal economy, knows with what precaution he should employ less known remedies; while he knows also, that even good remedies are only good when seasonably used. And this knowledge, so far from unfitting him for finding new remedies among the natural productions of a strange place, affords him an infinite advantage over every one who, without such knowledge, ventures to experiment upon a disease. Let a man understand the general scope of Physiology, and he becomes, under sickness or injury, a safe guide in the wilds of Australia; while he who is ignorant of the animal economy, if he uses remedies at all, uses them as much at random as in the days of spells, amulets, and charms. If he has studied Botany, he knows, as we shall presently see, from which families of the vegetable kingdom safe drugs may be taken, and from which poisonous substances may be feared.

Man, in every country, acquires the most part of his knowledge by experience; but in every complex kind of knowledge, like that which relates to man, animals, and plants, his experience deceives him, unless he be previously acquainted with the general scope of nature in that department. Hence a new settler in a strange country, who understands Physiology, has an immense advantage

over one whose ignorance does not allow him to interpret the things which daily come under his notice.

Psychology. — The vast recent progress of the physical sciences has cast into shade those important branches of knowledge which rest on thought retroverted upon itself. Such are the Psychological sciences, — Metaphysics, Logic, Ethics, etc.

However little has been the progress of an exact kind hitherto made in those sciences, there can be no doubt that man is both capable of making, and destined to make, great advances in those all-important departments of knowledge. If it be asked to what end? The answer is, that it is solely by the general diffusion of these sciences that language can be made an exact medium for the interchange of thought and opinion on all subjects which are not represented by sensible objects.

In no distant time the activity of mankind must require new occupation of mind. The career of physics, astronomy, and chemistry, must begin to slacken, if such a slackening has not already commenced. The world at present stands amazed at the successful application of the discoveries, not quite of recent date, in the physical and chemical departments, to the arts of life—steam navigation, gas illumination, railway communication, the electric telegraph, the advance of agriculture; but even these wonders must lose their novelty, and the time will arrive when the sciences of mind will have their turn of popular favour and cultivation, from which the most important fruits may be anticipated.

The stagnation of the psychological sciences extends to all those which rest upon moral evidence; in short, to all those which depend for their progress on precision of nomenclature, while the subjects of inquiry are not fully represented by sensible objects. There are, indeed, numerous departments of human knowledge which seem to depend on mere observation, in which general principles are continually deduced from apparent facts, while the progress made is very little commensurate with the labour bestowed upon them. This defect of progress arises chiefly from the so-called principles or inferences being deduced from particulars called by the same name, without being, as is necessary for a perfect induction, exactly identical in character. The Science of Government, the Science of Law, the Science of Medicine, and many other departments of human knowledge, come within this description.

Statistics. — Statistics have of late assumed the character of a separate branch of knowledge. It is rather an art than a science, and when unskilfully practised, is subject to the greatest possible fallacies in its deductions. The evidence of statistics is apt to be represented as equivalent to that of demonstration. But the slightest consideration will show that the evidence of statistics, though capable in some

circumstances of being demonstrative, also ranges through every degree of moral evidence — the possible, the probable, and the morally certain. Hence the source of the great errors just referred to, as often as the evidence of statistics is assumed to possess one uniform demonstrative character. It is manifest that in all kinds of induction the principles arrived at can have no higher authority than the evidence bearing on the identity of the several particulars out of which these principles have been drawn.

It seems unnecessary to go farther in illustration of the proposition that the various departments of knowledge, resting on moral evidence, cannot make effectual progress until the psychological sciences have gained a larger share of popular favour, and have become generally cultivated and understood.

Natural History.—Between Natural History and the descriptive sciences, a strict alliance has been closely cemented. In the advantages of this alliance both departments participate. Natural History was originally very rudely arranged, owing to the various mineral, vegetable, and animal species being grouped together, in accordance merely with their most obvious external characters. What are termed natural systems of Natural History have arisen out of its alliance with the descriptive sciences, — the knowledge of the minute structure of plants and animals, and of the structure and composition of mineral bodies being made subservient to the grouping together those individuals of the three kingdoms which are most closely related to each other in internal as well as in external characters.

Mineralogy. — What a field of profit to the student does Natural History present! In the inorganic kingdom, how precious is the knowledge by which he can, figuratively at least, convert dross into gold! If a man has become acquainted with the characters of mineral substances, he may discover that which is regarded as worthless to be often of the greatest value for some purpose in the arts. A recent action at law exhibited one of the parties as having obtained a lease for upwards of twenty years of a coal-mine, — one of bituminous shale, which yields many times the price of coal for the manufacture of gas. The lease was found valid. Now, had the proprietor known a little of mineralogy, instead of entering upon a costly law-suit, he might have enriched himself by selling his own stratum at its actual value. But numerous instances could easily be cited, in which similar ignorance of natural objects is tantamount to loss; and where, on the other hand, even a slight knowledge leads to great pecuniary benefit.

Knowledge of the Mineral Kingdom implies an acquaintance with the characters by which the precious stones are recognised; with the indications of the mineral forms of the useful metals; with

those of marbles, spars, alabasters, and ornamental minerals in general; with building stones, and their relative value; and with the minerals which characterise the several geological formations. All these subjects we propose to introduce in due time into our Treatises; and on how many occasions may our expositions of this description of knowledge prove of the utmost service in many positions of life! Let us state a case, as related by Professor Tennant in his Fifteenth Lecture, on the results of the Great Exhibition. For want of the knowledge of the crystalline form of the diamond, a gentleman in California offered £200 for a small specimen of quartz. The gentleman knew nothing of the substance, except that it was a bright, shining mineral, excessively hard, not to be touched by the file, and which would scratch glass. Presuming that these qualities belonged only to the diamond, he conceived that he was offering a fair price for the gem. The offer was declined by the owner; who, had he known that the diamond was never found crystallized in the form of a six-sided prism, terminated at each side by a six-sided pyramid, as seen in the larger cut, which is the exact size and shape of the stone, he would have been able to detect the fact, that that for which he was offered £200 was really not worth more than half-a-crown! The larger figure represents the piece of quartz in question; the smaller, one of the more common forms of the diamond.

Fig. 14.

Zoology.—Again, as to the Animal Kingdom, how large the mine of knowledge it embraces, and that of interest and importance not confined to the naturalist! The merchant, the manufacturer, the agriculturist, the traveller, the sportsman have all to seek aid, in

Fig. 15.

their several pursuits, from a knowledge of this department of natural history. Look to the value of our fisheries, and judge how available to the commercial world becomes this knowledge of animal nature. Nay more, but for our knowledge of natural history, one of our most important articles of food would in time have entirely disappeared from our waters. We allude to the salmon, the fry of which, and the parr, are now universally acknowledged to be identical. Our cut (No. 15) shows the fish so well known by the transverse dusky bars which mark its sides. Under the name of parr, it abounds in all salmon rivers; and, until the researches of Mr. Shaw, Sir Wm. Jardine, and others, proclaimed it to be the young of the salmon, it fell in thousands before the strategies of every village boy who possessed a crooked pin and a yard or two of line. Science has now established its value, and invoked regulations for its preservation. The angler too, — how much more successful is he in his sport who has studied the circumstances which influence the humours of his prey? Is it less true of the sportsman who unweariedly paces the moors in autumn that his success is intimately dependent on his knowledge of the habits of the game? The wild-goose chase is proverbial; but, besides the actual chase of the bird, in which no one succeeds who does not understand its habits, there are many figurative wild-goose chases in the animal kingdom in which success fails from ignorance of particulars, which the study of Natural History could easily have supplied. A practical illustration of the benefits even of a slight knowledge of Zoology, presents itself in the case of a traveller or emigrant in some unknown country. He has pitched his tent, or raised his hut; and then he finds the locality infested by serpents. He is all anxiety and fear. He knows not what to do: whether to proceed to another spot, or to remain and brave the danger. Some acquaintance with the structure of reptiles would at once have decided his plans; for with the first he killed he could decide whether they were venomous or

Fig. 16.

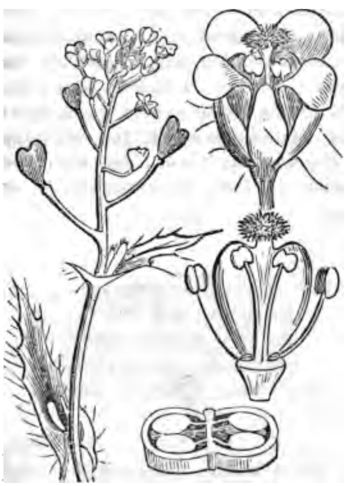
Fig. 17.

harmless. The former — and the common viper is one — possesses, on either side of the head, glands which secrete their venom; and, to conduct it to the wound they inflict upon their prey, they are

furnished with two hollow but long, recurved, and sharply pointed teeth in their upper jaw. The harmless serpents have no such apparatus; and thus the two genera are at once distinguished by the absence or presence of the fang in question. Our cut, (Figs. 16, 17,) after Professor Owen, exhibits the skulls of the two families with their dental peculiarities.

Botany. — A treatise might be written on the benefits which an acquaintance with the Vegetable Kingdom is capable of affording. Of how great use is it in strange countries to be able to distinguish the plants fit for food, from such as are poisonous; and to recognise those which have been employed in medicine, or in any one of the numerous arts to which the Vegetable Kingdom is subservient! Even an Elementary knowledge of Botany is of exceeding interest and importance. Travellers in unknown lands know full well that life or death often depends upon their acquaintance with the science — an acquaintance, it may be, not derived from learned treatises, but simply from little more than the ordinary observation of those edible plants with which all persons are familiar. But even this is still a knowledge of Botany. An all-wise Providence has so arranged that plants may be associated into families from their external resemblances; and, further, that plants possessing such resemblances to each other, have many properties in common.

FIG. 18.



One of the great families of plants is the Cruciferæ, or Turnip tribe, every member of which, marked by very obvious characters, is easily recognised, and scarcely to be mistaken; and all are remarkable for edible and antiscorbutic properties. The crew which accompanied Vancouver in the expedition of 1792, suffered severely from scurvy, from want of vegetable food. The surgeon advised that they should make for the first land; and at Cape Horn he found a plant resembling spinach, which he directed to be used as food, with the happiest effects. This is not a rule without an exception; but it is of such universal application that the traveller may in his necessity, safely trust himself to its guidance.

The Icosandrous plants, or such as have an indefinite number of stamens attached to the calyx, are remarkable for their fidelity to this law. They are all edible, and are represented by the apple and pear tribes, the cherry, the strawberry, &c.

FIG. 19.

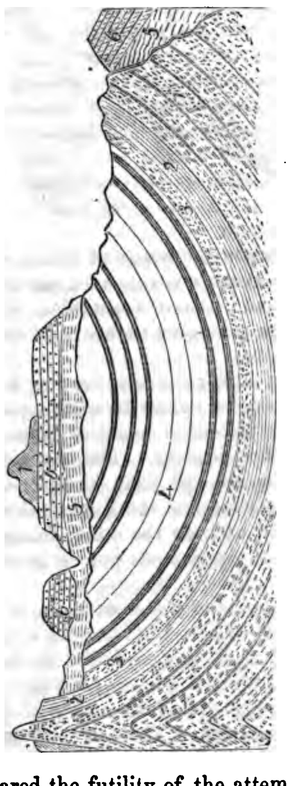
There is also another great family — the grasses, the members of which exceed those of any other class, in number and in their essential importance to the whole animal creation. This family comprehends the grasses, commonly so called — the wheat, oat, barley, rye, &c., of our temperate climate, and the sugar canes of tropical regions; and all possess the common properties of being nutritious and healthful. During Lord Anson's voyages, on the failure of provisions, the mariners landed and found vegetables, which, although unknown, were recognised as belonging to this great family, and proved to be highly beneficial.

But while the value of this law is indisputable, a further knowledge of Botany is necessary to the traveller; since he will frequently find associated together edible and poisonous plants. Thus, the deadly Upas tree is placed with the delicious fig. The magnificent Euphorbias of tropical forests yield, on the one hand, the refreshing juice of the E. Balsamifera of the Canaries, and the Yuca Dulce, the nutritious farinaceous meal of Mexico; and, on the other, furnish to the warlike inhabitants of Ethiopia the poisonous juices in which they dip their arrows.

The splendid Cactuses, also, produce the delicious milk of the Hya-hya, in British Guiana, and that of the Cow tree in Ceylon, and also furnish the strychnine of medicine, and the far-famed wouralie poison of the banks of the Orinoco. Lastly, it frequently happens that, while one part of the plant yields an article of food, another is laden with noxious properties. Thus, if the starch furnished by the Euphorbias and Cactuses were eaten before the juices of the plants were expelled, speedy death would ensue; and, as a more familiar example, the tubers of the potatoe plant form a valuable article of diet, while its green-coloured fruit is poisonous.

Geology. — Geology, again, is no longer a merely curious speculation. On the contrary, it is one of the sciences which most surely leads to practical results. It has methodised the crust of the earth, and taught us to look for certain minerals almost as we look for certain books upon certain shelves of a library. Coal is nowhere found but in the coal-measures; and a knowledge of the position of the coal or ironstone strata, and of the rocks usually associated with them, has guided the capitalist to the spot where he might engage in the search for these products with the least chance of disappointment; and, in many instances, had the directions of Science been sought and followed, vast sums would have been saved to the community.

FIG. 20.



1. Old Red Sandstone. 2. Mountain Limestone. 3. Millstone Grit. 4. Coal Measures. 5. New Red Sandstone. 6. Lias. 7. Superior Oolite.

Deceived by appearances, or misled by designing individuals, persons have sought coal at a great expense in the wealden formation of Sussex, the oolites of Oxfordshire and Northamptonshire, and among the silurians of Radnorshire; whereas attention to the simplest principles of Geology would have shown the folly of such attempts. Because Pennsylvania is rich in coal, it was imagined, in the neighbouring state of New York, that the precious gift might also be found there; and the resemblance of certain silurian rocks, on the banks of the Hudson, to the bituminous shales of the true coal formation, appeared to sanction the surmise. Accordingly, mining adventurers squandered away a large amount of capital; until Geology, at the invitation of the Legislature, authoritatively declared the futility of the attempts.

Our cut exhibits a section of the Great Bristol Coal-field, extending from the Mendip Hills to the north-west of Bath, a distance of about twenty miles.

Arrangement of Knowledge. — Besides the Sciences and the Liberal Arts, which last will obtain a due share of our attention, there are, among the subjects of human knowledge, the Arts and Manufactures, which contribute to the convenience and comfort of life; and which may be classed under the general head of Social Economy.

The various branches of knowledge of a practical kind connect themselves with corresponding branches of Science. Some arts are mechanical; some chemical; some physiological, and some purely intellectual. In all these departments there are practical branches of knowledge which deserve the attention of every one who desires to be accounted liberally educated; while there are others too technical to admit of any proficiency except on the part of those who devote their lives to the pursuit. Arts of this latter description will not enter into our plan; but, in other respects, we shall exclude no branch of study which belongs to the education of an accomplished citizen.

It is thus seen that the mode in which we design to treat our subjects is such as best conduces to exercise and improve the human faculties, and to open and expand the mind.

Uses of Knowledge. — The acquisition of knowledge has two great objects; namely, to obtain information for its own sake—that is, for the sake of the uses to which that information may be applied; and also, by the varied exercise of apprehension, memory, reasoning, judgment, and other powers of the intellect, to render those faculties available for the purposes, however great, in which, one time or other, a man's position in life may require their utmost service.

The effect of education upon the individual is easily understood. It makes him what he actually is, as respects the particular stores of knowledge he possesses, and the command of mind which he can bring to bear on every crisis of his life. But man in society does not stand insulated, either as respects his knowledge or his powers of exertion. Every man possessed of knowledge and of ability, natural or acquired, sheds around him gifts of incalculable value. He is a centre or focus from which light is diffused on every side. A person who is himself uneducated, by living among those who are educated, obtains no small share of the advantages which they possess. He picks up fragments of their knowledge; but by far the greatest of his gains arises from the circumstance that, by the imitative power with which our species is so largely gifted, he catches the spirit of the acquired modes of thinking possessed by those around him; so that, although his knowledge may remain rude and disjointed, he begins to think like one who has received a liberal education. Thus, like charity, knowledge carries with it a double blessing—blessing him that offers, and him that receives.

Perhaps no people as a body ever exceeded the Athenians in acuteness. This we may justly infer from the style of the orations addressed to them, particularly from the stern, direct character of those of Demosthenes. To the immediate education of the Athenian youth no very great attention appears to have been paid. We are told that their first instruction was in swimming and the rudiments of literature. As for those whose abilities were but mean, they were to learn husbandry, manufactures, and trades. Those who could afford the education of a gentleman were to learn to play upon musical instruments, to ride, to study philosophy, to hunt, and practise gymnastics. Whence, then, did the Athenians as a body acquire that reputation for acuteness, for which, undoubtedly, they were pre-eminent? The portion of the people to which this character applied, probably at no period exceeded thirty thousand, if, indeed, that be not too high an estimate; since it only excludes the servants and bondmen, by far the most considerable proportion of the inhabitants, and makes allowance for about ten thousand foreigners, who were permitted to listen, but not to take part in public affairs, or in public amusements.

The signal acuteness of the Athenians arose, unquestionably, not from any remarkable superiority in their early education, but from the public life which they lived, continually listening, in their public assemblies and courts of justice, to orators; in the schools of philosophy, to discourses on human nature rather than on physical science; and in the theatres, to the unrivalled dramas of their tragedians and comic writers. Thus an Athenian, when Athens was at the height of its fame, could not be otherwise than acute. He took part in the deliberations regarding public affairs; he was present whenever instruction or amusement was going forward; and, if war arose, he fought,—sometimes by sea, sometimes by land. He had occasion for no language but his own; his instruction was chiefly oral; he required no books but those written almost in his own time; and he could not but know his own language in all its minuteness and shades of meaning. He was a statesman, a legislator, a lawyer, a soldier, a philosopher, and a man of taste; he was therefore master of all the technicalities which had as yet arisen in the language; and nothing could be spoken of, or even hinted at, which he did not at once perceive and understand.

How different is the case in modern times! How much more must be learned to be on a level with the age than was necessary in Athens! At Athens the knowledge and acuteness by which an accomplished citizen was distinguished, came to him as easily as an acquaintance with town life now comes to those hopeful scions who spend their nights and days in the metropolitan streets.

We cite the superior acuteness of the Athenians to illustrate the effect of the spread of intelligence from mind to mind, by which the improvement of a small proportion of the population becomes a sort of leaven to the whole mass, which, under favourable circumstances, may quickly become similarly affected. But the history of the Athenian people affords us another lesson, by showing how much the world has changed since their time, and how much more laborious is now the task of acquiring knowledge, and a character for intelligence and acuteness; for, in our day, owing to the rapid extension of new departments of knowledge, and the consequent increase of new terms, there is no longer that general acquaintance with the meaning of words which prevailed among the ancient inhabitants of Athens.

Popular Errors. — We admit that, in the course of time, society, merely by having included within it a small sprinkling of persons imbued with exact knowledge, has come to think correctly upon a great number of subjects, on which formerly the grossest errors prevailed. But this very circumstance affords the strongest inducement to promote education, with the utmost speed, through every rank of the community. There are still many evils more or less latently devastating the social fabric, which an improved state of knowledge, and the consequent more exact mode of thinking, would go far to correct. It is an undeniable fact, that within the last two or three hundred years a vast amount of positive delusion, by which the human faculties, moral and intellectual, were for ages kept in thraldom, has almost wholly disappeared from western Europe. Now, if men in general no longer seek to discover the coming incidents of a man's life, or distant events in the history of a people, by studying the course of the stars or to prefigure the future in the direction of a thunder-clap, or in a shower of stones from the air, or in the flight of a bird, or in some peculiarity of an animal's entrails,—and that less from any profound or widely-diffused knowledge bearing on such subjects, than from a more exact mode of thinking on the course of nature derived from the increasing, though still small proportion of educated minds influencing society — surely there is ground to anticipate that many of the evils still left behind — the fruits of ignorance and unsound thinking — would be eradicated by the general diffusion of education throughout the masses of the community.

Ignorance of Natural Laws. — How slight is the knowledge of the laws of nature, which for the last two or three hundred years has fallen to the lot of each individual, even among the educated orders of society! And yet that mere sprinkling of knowledge in such sciences as Astronomy, Meteorology, Natural History, and

Anatomy, has sufficed to banish from this part of the world astrology, divination, sorcery, witchcraft, and magic. What an encouragement does this fact afford to perseverance in that course which, within the narrowest limits, has proved so successful! But there are still delusions remaining to be banished by the extension of sound knowledge. Does the favour extended by the public to clairvoyance, table-turning, and spirit-rapping tell of the advancement of our age beyond the standard of a former one? The age should blush for itself, and take to study. Such study would not only teach what to believe in matters of science, but put it fairly on its guard against blind guides, who every now and then arise, like *ignes fatui*, to mislead the unwary. There are two brilliant examples of these in the present day, who may serve as lessons to the public in the time to come, as having led many astray from the simplicity of truth. They are distinguished men, too — the one an eminent chemist of Germany, the other, one of the greatest men Scotland has produced. The public should prize both these men much, but truth more. It is melancholy to think that such men should outlive their faculties; but it is still more melancholy to think that the public should be so little instructed as not to distinguish true from false science.

Statistic Fallacies. — The tendencies of the present age have caused exactness, where men must think without sensible forms before them, to be so generally neglected, that authors who would lose caste and reputation for bad spelling, and still more, for errors in grammar, may violate with impunity the rules of logic, so essential to the teaching of truth. In no department are these rules so often grossly violated as in statistical subjects, where we should certainly expect something like mathematical accuracy. Mr. Farr, the able medical assistant of the Registrar-General, has pointed out a most ludicrous mistake of a logical kind, which cannot be too widely exposed in an age when every man appeals to statistics, and deems himself competent to deal with them. The annual mortality in prison-life being required, the statist takes the number of persons who have sojourned in a particular prison during the year, and also the number of deaths that have occurred. He then divides the former by the latter, and points to the result. Such logic is the same as if an innkeeper should boast of the healthiness of his house, as compared to the rest of the town, on the ground that he had, during the year, entertained a thousand guests, of whom only one had died; whereas, the mortality for the rest of the town had been at the rate of twelve per thousand. On this kind of logic, however, Mr. Farr tells us that a French minister pronounced prisons to be the healthiest places in the world; and an English inspector gravely affirmed, that in very few situations in life is an adult less likely to die than in a well-conducted prison!

False Induction. — In the ridiculous book of one of the persons to whom we have referred, translated by an eminent professor of chemistry, there is a most unpardonable abuse of the term "induction." One of the purposes of the work is to maintain that some people can see lights assuming the form of human bodies in church-yards, and other places where persons have been buried; and we are told that the evidence on which the German author rests this statement is an induction of particulars.

Now, what is this so-called induction of particulars? A lady repeatedly says that she sees luminous forms over the graves of the newly-buried. Each repetition of the assertion is gravely set down as one of such a series of particulars, as upon which it is allowed to found an induction. In the first place, there is no evidence of even one of her assertions being founded upon anything but a vagary of the imagination. It is a correct induction, from the particular instances referred to, to say that the lady in question asserts such things; but here the induction ends, and, as regards the reality of the things seen, one assertion is as good as a thousand.

It is melancholy to think that such credulity should exist among men of eminence in special departments of human knowledge; but still more melancholy to reflect that the very terms of exact logic should be misunderstood by an eminent professor of an important department of Physical Science.

Education. — The sentiment, so long tolerated in this country, that education might prove hurtful to the masses of society, and unfit them for their ordinary occupations, has long since either died a natural death, or, if not dead, is content to hide its diminished head in some unvisited corner of the land. Nevertheless it is not altogether a settled point what kind of education should be provided for the public. Some simple-minded people limit their notion of education to the humble acquirements of reading and writing; and persons of this stamp are often heard to express their surprise when they discover that a large portion of our criminal population are masters of these accomplishments. Reading and writing are but the instruments by which education is acquired. And it has been a strange oversight that so much pains have been bestowed in providing our population with the instruments of education, while so few have taken thought to put within their reach the books from which the knowledge yearned after could be reached. To supply in part this want is the great purpose of our present undertaking; and if those who express their surprise that there are among public criminals persons who can read and write, would extend their ideas of education to what includes some acquired knowledge of God, of Man, and of Nature, they would confess that crimes are seldom committed by sound-minded and educated people.

We have asserted that reading and writing are not education, but rather the instruments by which knowledge is to be acquired. It must be admitted, however, that some limitation may be required to this sentiment; since it might be contended that reading and writing stand, in some measure, on the same footing as the several branches of what has been termed "industrial education." But although industrial education, in its special sense, signifies merely that sort of training by which a person may be rendered more apt to learn the kind of occupation which is to be his calling throughout life, and more capable of attaining excellence in it; yet such an education has an additional influence in developing the faculties, both intellectual and moral, far beyond what the mere accomplishments of reading and writing can produce.

Important as industrial education is, for the simple purpose of aiding the development of industry, we must never lose sight of its subsidiary effect in exalting the intellectual and moral character of the individual; nor is it to be doubted that the very best effects may be anticipated from mingling in all schemes of industrial education such studies as belong to Physiology and Psychology, together with those of a directly industrial character, in order to secure a more immediate influence upon the moral character.

There can be no doubt that it is possible so to direct industrial education as to destroy much of the benefit which it is capable of conferring. There is nothing in the study of abstract science and physical knowledge which should withdraw the mind from an acknowledgment of the existence of the SPIRITUAL in the economy of nature. But there is a mode of studying these subjects which makes the properties and laws of matter terminate too much in themselves, without sufficient reference to the power of the INFINITE INTELLIGENCE by which they are maintained and supported.

In all systems of industrial education it should be a first principle that the power which operates in the workings of nature should stand forth acknowledged as the POWER OF GOD; and that man's power of thinking should be confessed as being the foundation of all that his mere senses seem to have discovered of the course of nature.

The term observation is likely to mislead the unwary, who are so often told that all human advancement depends upon observation that they are apt to forget that observation may serve to perpetuate error as readily as to advance truth. They lose sight of the essential maxim that it is instructed observation that at once discards error and establishes truth. It is indeed difficult for an enthusiastic student, amid the profusion of knowledge now set before him, not to believe that all that is necessary to enable an unprejudiced person to understand the order and course of nature, is simply to open his eyes

and look around him. It is, then, an instructive lesson for him to discover that, by the same exercise of the senses which seems at once to have laid open the secrets of the universe, all those phantoms, which for so many centuries deluded the human mind, took their origin.

What we here desire to insist upon is, the paramount influence of the state of man's spiritual development at any one time upon his capability of apprehending the economy of nature, with regard to the axiom—that the study of the agency by which knowledge is acquired should never be severed from the study of the things which are made the objects of knowledge.

It is a common idea that the rapid progress of modern science has arisen entirely from a diligent use of the senses, in obedience to the precepts of the Baconian Philosophy. The vast progress of human thought, previous to the possibility of this advantageous use of the senses, is too often altogether overlooked. Thus sense is exalted at the expense of the higher faculties of the mind, and the conclusion arrived at, that the education of the sentient part of our nature is all in all. How erroneous is this idea, will at once appear from the briefest retrospect of the history of man's progress. In man's rudest state there is no want of what passes for knowledge; and his mind is so far from being barren in that stage of progress, or his memory destitute of ideas, that he positively bends under the burden of his thoughts and recollections. Nevertheless, the greater part of this profusion of apparent knowledge with which his mind is filled is entirely false. In a somewhat later stage of progress, this early mass of delusion is represented by the more refined but equally worthless products of sorcery, magic, witchcraft, divination, and astrology.

When we look to the history of man in the first rude ages, we discover an appalling amount of delusion, which we admit has arisen from this tendency to account for what he sees; but, side by side with this heap of rubbish, we find surprising proofs of the exactness with which he has gathered up such laws of nature as are most essential to his every-day well-being. It is when the phenomena are of rarer occurrence, or when they are complex, or when they seldom arise under exactly the same form, that he falls into error. On the contrary, when phenomena come frequently under his notice, if he has erred at first, he commonly obtains the means of rectifying his error. As soon as he discovers distinctly that the succession is not invariable, he ceases to regard the two events as standing in the relation of cause and effect.

It would be easy, then, to show that no just reproach can be thrown against this principle of man's mental constitution. All that he knows of cause and effect he has acquired by a reliance on this

part of his mental endowments; and we may justly remark that, in the early stages of his progress, he must have been led to expect, through this principle, the discovery of things placed beyond his reach, owing to the great success with which he had applied the same to the acquisition of knowledge fit for the supply of his every-day wants.

Astrology, divination, sorcery, witchcraft, and magic, are all pursuits seeking to attain a knowledge and power forbidden to man. To these pursuits, doubtless, he was led by this belief, that when two events stand in immediate succession, the first is the cause of the second. By these studies he sought an unattainable knowledge of the future, and an unattainable power over the future; he was dealing with obscure phenomena; he could not readily discover the test afforded by a distinct failure in the succession; and hence these subjects grew to the extent in which history exhibits them. But, during all that while, the knowledge of real causes and real effects was accumulating; and as this real knowledge successively laid open the true order and course of nature, the supposed means of gaining knowledge and power, as respects the future, began to decline.

What we contend for is, the necessity of directing education to the knowledge of the workings of the human mind, as well as to the study of the laws of nature. This we must repeat in season and out of season; and we think we have just shown, by a sufficient detail of facts, that man's knowledge of the course of nature is correct only in so far as he understands the real character of that intelligent agency, his own mind, by which alone, upon earth, the operations of nature are fathomed.

It is a great error to attempt to reduce popular education to a low standard. The power of thinking, and even of thinking deeply, naturally belongs to all sound-minded men. It is the complexity of many subjects of knowledge that have risen up among men which creates the chief difficulty in popular education; and that difficulty is, above all, aggravated by the technicalities of words and symbols, which have been perhaps unnecessarily affected, particularly by those who ridicule the idea of popular education in the profounder parts of knowledge. It is quite true that access to the most profound and exact parts of Physical Science can only be obtained through the abstruse means of mathematical investigation. But there is no room for despair. Although it is impossible, without the application of more time and labour than can be spared by the busy world, to gain a practical acquaintance with the profound means of mathematical investigation, it is within the reach of every one to gain tolerably just ideas of the nature of those powerful instruments of research. All mathematical truth rests, as we have seen, on intuitive principles

of the human mind, independently of all experience; and by approaching Mathematics on this side, that is, by considering the fundamental principles of Mathematics in their logical form, not only are the mental faculties enlarged and expanded, but the want of an intimate knowledge of its details is, in no slight degree, supplied to the student of the general economy of nature. To present the various departments of Mathematics in what may be termed their metaphysical form, should be an object with all those concerned in devising the means of placing an enlarged education within the reach of the public. It is not to be wished that men engaged in active pursuits should immerse themselves in the deep cultivation of modern mathematics. Geometry, in the prosecution of which every step is made clear to the mind, cannot but serve to expand the faculties; but the higher departments of Mathematics render the operator too much of a machine, and, unless when the mind is happily constituted, are very apt to spoil the faculties for use in the ordinary concerns of life.

Opinions and Principles.—At the commencement of an undertaking which involves so wide a range of discussion, it is incumbent upon us to make a profession of the rule by which we are to be governed on all those occasions when, in the capacity of instructors, we have to enter upon certain momentous questions that cannot be better indicated than as falling under the heads of OPINIONS and PRINCIPLES.

Our paramount rule will be the love of truth. We repudiate the materialism which at present contaminates so much of our popular literature on subjects of science. We shall endeavour to show how groundless—how unphilosophical—are such views of the economy of the universe. We shall take pains, as often as an opportunity occurs, to make it clear to our readers that the faculties of the human mind are qualified to discover something greater than mere law in the economy of nature. We do not fear to promise that the proof of the operation and superintendence of an INFINITE AND PERSONAL INTELLIGENCE will be as completely exhibited as that of the existence of any of the laws of nature which man has discovered.

We shall, on all proper occasions, combat the erroneous notion, now so generally inculcated, that the discovery of a law includes all that the human mind can derive from the contemplation of nature. We know how plausible this notion may be made to appear; and how fascinating it is to think that all the complex operations of nature can be reduced within the limits of a few general laws. But we know also how many are deceived into the belief that such an explanation of the phenomena is satisfactory to the human mind, as including all which, by its constitution, it desires in the search into

nature. But do the popular writers who have adopted these views tell their disciples that this specious system of law is designed to supersede all idea of cause—all idea of efficiency—all idea of power—all idea of an overruling Intelligence? It will be easy to show that such is the case, notwithstanding that some may protest that, while they insist upon the universality of law, they never fail to profess their belief in an Omnipotent Creator. We admit that it is so; but we say that it requires but small penetration to see that their logic leaves no room for that GOD in whom their lips alone profess a belief.

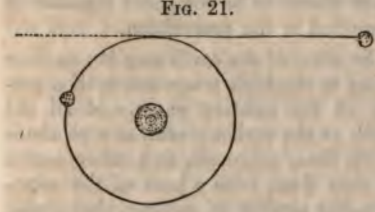
Further, we affirm, and challenge contradiction, that the great apostle of such views, from whose works the ideas and reasonings of these writers are chiefly drawn, makes no such limitation in his doctrines; but, on the contrary, he explicitly declares that the age of theology in human science is gone by—meaning, by that expression, that the doctrine of universal law has superseded the idea of a Creator.

We know that some persons cherish the notion that the light of nature cannot carry men to the knowledge of GOD. We will not, however, enter into debate on this point at present; we will only remind those to whom our argument may suggest this sentiment, that what we are contending against is altogether different—namely, the proposition latent in many popular treatises, that human science is positively adverse to the belief in a SUPREME INTELLIGENCE.

It would not surprise us if many of those who have become fascinated with the apparent simplicity of that philosophy which insists upon the universality of law, should persuade themselves that we are misrepresenting their favourite system. They have not discovered that the system involves the denial of an intelligent and infinite FIRST CAUSE. We have already reminded them that the great modern apostle of the doctrines to which they listen with so much satisfaction expressly says, however seldom the impious words may have been allowed to reach their ears, that philosophy finds no place for God in nature. This philosopher is a most dangerous logician. It is not in his reasoning that flaws are discoverable; it is in his first principles,—and these first principles are exactly those which they have been seduced to think favourably of. Let them not forget that a rigid logic brings out falsehood as certainly as truth, if the principles be false. Among these first principles, all the victims of this system of universal law, we have no doubt, are well familiarized with that which enunciates that, between any two events in nature reputed to stand to each other in the relation of cause and effect, there is no link discoverable except invariable sequence; or that nothing more can be known of their connection, except that the one is uniformly the antecedent of the other—the second the uniform consequent of

the first. It follows from this proposition, when stated as above, without any qualification, that the term "cause" is superfluous in reference to the changes which take place in the economy of nature. Authors who have adopted such views, still employ the term cause; but when we examine the use they make of that term, we find it to be exactly synonymous with law. For example, if the question be asked what is the cause of the curvilinear path of the planets, and the answer is, that the attraction of the sun draws them from the straight line, the cause here assigned is manifestly nothing more than a reference to the law of gravitation. The question would have been answered in exactly equivalent terms, if it had been said, by the law of gravitation, two bodies moving otherwise than in the same straight line deflect each other into a curvilinear orbit; and if the one be much inferior to the other in magnitude, the less will circulate around the greater.

Fig. 21.



If, then, there be no case, in the whole of nature, in which, when a change takes place, anything more can be discovered than that an invariable antecedent has been succeeded by an invariable consequent, there is no case in which the term *cause* is applicable in any other sense than as expressive of the law under which the change in question falls, if such a law has been discovered. And if no law including the change has been discovered, then no cause can be assigned beyond the affirmation that such and such a phenomenon has been invariably observed to succeed another phenomenon; that is to say, as a particular instance of an undiscovered law. If, then, man can discover nothing but law in nature, there is no separate sense for the term cause; and if there is no room for the term cause, then there is no known instance of the evercise of power. And if man be incapable of discovering the exercise of power in the universe, then he is incapable of discovering the hand of God; for what is God in nature but Infinite, Intelligent Power? Such is the logical conclusion from the unqualified statement that nothing is discoverable by man, in the investigation of the operations of nature, but a mere sequence of phenomena.

But to this proposition we maintain that an important addition is indispensable. Man cannot, indeed, discover anything but invariable sequence in the phenomena of nature; but he never sees two phenomena thus succeed each other in invariable sequence, without an involuntary acknowledgment than an exercise of power has taken

place. This is the addition required to the doctrine of law in physical science; and this feeling of the exercise of power, as often as a change is seen to take place in the universe, is easily proved to be the light of nature, at every moment suggesting to men's minds the presence of Omnipotence.

This point admits of easy illustration. That our earth was once destitute of every living thing, plant, or animal on its surface, admits of the clearest evidence. At a period, how distant from our time is immaterial, the earth became stocked with plants and animals. Here, then, are two states of our planet to be compared together in reference to the signal change implied in the proposition.

We clearly understand that the crust of the earth may at one time have been in a liquid state, owing to the high temperature then prevailing at the surface. Hence all the existing water, and all the volatile chemical compounds, such as the carbonic acid, now so abundantly known in combination with lime, magnesia, and other earths and metallic oxides, would, at that time, form a part of the atmosphere. But by the simple familiar process of cooling, that crust, in the course of ages, would become solidified; the water, along with the less volatile bodies, would descend to the surface, and, dissolving the soluble substances with which it came in contact, would create in them new arrangements, from which the present character of many parts of the crust of the earth would be derived. In such changes nothing is apparent but the activity of laws and properties known to belong at this moment to the Mineral Kingdom.

But although it be now known, from the evidence of chemical analysis, that all the members of the Animal and Vegetable Kingdoms are entirely composed of materials to be met with in the crust of the earth, never has any one property of mineral matter come to light, from which it could be justly conjectured that there is any natural tendency, in the mineral substances composing organic bodies, to pass from the mineral state into any forms of organization, however simple. Here observation is completely at fault. No fact exists to form the very embryo of an induction. The doctrine of equivocal generation held its ground, only while uninvestigated; and the alleged results of the experiments of Mr. Crosse, which, if correct, would have been so easily authenticated, are believed by nobody but the credulous and partially instructed. To say that we are entitled to assume that the germs of the organic bodies exist in the minerals of the earth, is to revert to the philosophy of the ancients—to throw aside the precepts of Bacon—to forget that induction consists in first discovering facts, and then principles. If it be

said that this is merely an hypothesis brought forward to stimulate inquiry, we simply reply that an hypothesis which has not the shadow of a fact in its favour is no better than an idle dream.

We maintain, then, that the contemplation of the transition of the earth, from a state destitute of living things to one teeming with life, forces upon the human mind, by its very constitution, the conviction that in that vast change, so irreconcileable with the ordinary properties of the mineral matter out of which the organic world has arisen, there has been an exercise of POWER—that is, of a PERSONAL INTELLIGENCE—commensurate with the wonders of the work which has been accomplished.

The philosophy, then, to which we shall uniformly conform throughout our undertaking is easily understood. We set out with the belief that there are other truths within man's reach besides those determined by observation. There are, in the first place, certain necessary truths, which, independently of all observation and experience, man, by the very constituent of his nature, must believe. Of these some are intuitive, and others established by reasoning back to the intuitive truths. The conviction in each individual of his personal identity, and of the reality of all acts of consciousness, are intuitive necessary truths — also such propositions as that, when equals are taken from equals, equals remain; that things which are equal to the same are equal to one another; that things which are doubles or halves of the same, are equal to one another; that twice four are eight; and that when two are taken from four two remain. All Mathematical demonstrations are necessary truths, not intuitive, but resting upon intuitive necessary truths, being established by reasoning back to such truths; for example, that the angle in a semicircle is a right angle, and that two tangents to a circle drawn in opposite directions from the same point are equal.

There are also intuitive truths which are not necessary truths, — that is, intuitive truths, the opposite of which, or a greater or less deviation from which, does not involve a contradiction. The intuitive truths which are not necessary truths, are such convictions as the belief in an external world, and in the free agency of self; the feeling that every event has a cause; and that there is an exercise of power whenever a natural event takes place. There are also truths obtained by reasoning back to those intuitive truths. For example, by reasoning back to the two truths that every event has a cause, and that an exercise of power is felt to have occurred whenever a natural event takes place, we obtain the conclusion, as soon as we can combine with these the observation of the infinite extent of the universe, that there is an INFINITE OMNIPOTENT CAUSE.

Such truths we regard as the first principles on which the superstructure of man's knowledge rests. When this acknowledgment is made, we may embark on the wide ocean of physical investigation, without fear of reaching those impious conclusions to which we have above referred.

When we add, that every proper occasion will be seized to develope the true grounds on which Teleology rests, without at all infringing upon the precepts of Bacon with regard to the possible abuse of final causes in philosophical investigations, we think we have sufficiently indicated the character which this work will sustain as respects OPINIONS AND PRINCIPLES.

THE PHYSIOLOGY

OF

ANIMAL AND VEGETABLE LIFE.

Order in Physiology.—The Physiology of Animal and Vegetable Life, being a subject of great extent, must be methodically treated; and first, it is necessary to determine what principle of arrangement is to be adopted, in order to exhibit, in a connected form, the complete phenomena of these kinds of existence. There are several modes in which such phenomena have been methodized; and it will be convenient briefly to consider some of these, as exhibiting a general view of the whole subject.

The phenomena of animal and vegetable life may be described as Mechanical Phenomena, Chemical Phenomena, Electrical Phenomena, and the peculiar Phenomena of Excitability—the first three orders being common to all departments of nature. A great part of many of the most important actions of the perfect animal body are purely mechanical or purely chemical, or partly chemical or partly mechanical; while such actions are, in their remaining part, the result of a peculiar excitability. In the circulation of the blood, for example, in man, and in the animals resembling man, the blood is propelled onwards by mechanical forces, while these mechanical forces are called into activity in obedience to the laws of excitability. In the function of respiration the air enters the lungs in conformity with the laws of that part of mechanical science termed Pneumatics. The change which the blood undergoes by the contact of this air is a chemical change, or a change closely analogous to a chemical change; while these laws of pneumatics, and the chemical laws, are brought into operation by the agency of an organic excitability. The fluids contained in the leaves of plants in contact with atmospheric air, by the influence of light, undergo a chemical change, or a change exactly

analogous to a chemical change; while the leaf presents its upper surface to the light, under the direction of a peculiar excitability.

Excitability, however, can hardly be defined; and in the present state of physiology it is more a negative than a positive term. All the properties of an organic tissue, whether from the animal or from the vegetable kingdom, which are neither mechanical nor chemical, fall under excitability. Thus, excitability is that which renders animal and vegetable tissues susceptible of certain phenomena, different from the phenomena produced by the same causes on inert matter. For example, with inert matter, the form and textures of a leaf may be exactly imitated; but such an artificial leaf will be destitute of the susceptibility to turn towards the light in sunshine.

Under these several heads all the phenomena of plants and animals might probably be arranged; but the arangement would be far from convenient.

It belongs to the arrangement of the phenomena of organic life to point out what distinction exists between an organic body and inert matter; and the extreme divisibility of inert matter supplies the readiest ground of distinction. The divisibility of inert matter is either infinite, or, at least, such that no limit can be assigned to it—the minutest portion still retaining all the properties of the original mass. An organic body, on the contrary, is destroyed by division. Again, it seems a universal law, that living bodies alone can give origin to other living beings, either by a partial division of themselves, or by the process of generation; whereas the origin of inorganic substances is always quite independent of any pre-existing substance of a similar kind. Finally, the actions of organic substances, having attained their acme of intensity, gradually decay, and at length, from causes which are inherent in each individual, cease altogether, when the substance becomes at once amenable to the operations of merely chemical and mechanical agents. Such is not the case, however, with inorganic substances, which maintain the same state unalterably, and for any length of time, provided no external agents are brought to operate upon them.

But, from the very earliest times, it has been perceived that a kind of agreement exists between plants and animals; and that, in certain respects, both possess a common nature. In the fifth century before the Christian era, Empedocles taught that seeds are the true eggs of plants; and that plants, like animals, exhibit difference of sex, and a degree of sensibility. Setting out with the idea of this common nature of plants and animals, philosophers naturally next sought to discover some prominent mark of distinction between the two kinds of organic existence. Since the time of Aristotle, in the fourth century before the Christian era, the search after such a distinction has been often renewed; yet, strange to say, almost every

distinction hitherto fixed upon, though sufficiently obvious when confined to the higher orders of plants and animals, has been found to fail when applied to discriminate those organic beings lying on the confines of the two kingdoms. The distinction pointed out by Aristotle has been revived in recent times, though hardly with the expected success. This distinction proceeds on the ground that animals receive their nutriment into an internal cavity before it is absorbed into the substance of the body; that plants, on the contrary, absorb their nourishment by the external surface. Animals, in short, have a mouth and stomach; while plants feed by the spongioles of their radicles, and by their leaves.

While this distinction to a very great extent holds good, it cannot be affirmed that it has supplied an adequate test in doubtful cases.

The most recent test suggested for distinguishing whether an organic existence of doubtful aspect belongs to the vegetable or to the animal kingdom, is of a chemical character. Starch is a constituent of vegetable tissues; and by the blue colour which iodine imparts to starch, even when present in the most minute proportion, it can be detected, wherever it exists, with the greatest facility. This substance, starch, then, being supposed not to exist in the animal kingdom, promised to solve the long-studied problem, or, at least, to be the only test of distinction which, until very lately, could hold its ground; but the recent researches of some German physiologists have demonstrated the existence of particles of an amylaceous nature in some of the lower animals; and even in the brain and spinal cord of man a substance, termed cellulose, hitherto presumed to be proper to vegetables, has been discovered.

It is not to be concluded, however, because so great a difficulty occurs in discriminating from each other those plants and animals which stand on the confines of the two kingdoms, that the laws governing the vegetable economy are identical with those governing the animal economy.

On this important point, we will cite the following passage from the recent work of one of the most distinguished of living physiologists (*Valentin's Physiology*, by Brinton):—

"The constant physical and chemical changes which accompany life depend upon various exchanges, which are produced by the work of the different parts of the body — the extrusion of what is useless; the assimilation of what is received; and the restoration of the organs, by which all these operations are effected. The whole of the *vegetable* or *general organic functions* on which nutrition and generation depend, are repeated in every living body. It has often been supposed that all their particulars correspond in the two organic kingdoms; that there is a digestion, a respiration, a perspiration, and an excretion, in plants as well as animals. But a more accurate

examination teaches that this is not the case. Vegetables possess no tissues which allow of the same kind of nutritive absorption, of distribution of juices, or of secretion, that we meet with in, at least, the higher animals. They have no large cavities in which considerable quantities of food can be collected and dissolved by special fluid secretions. They possess no point midway in the movement of their juices, and no mechanism, other than that of a casual and secondary apparatus for the inhaustion or the expulsion of the respiratory gases. They are devoid of the changeable epithelial coverings, which play an important part in many of the animal excretory organs. In one word, the general organic functions are introduced into the two living kingdoms of nature, and probably into their subordinate divisions, by two different ways. This difference leads at once to the conclusion, that the structure of the animal is not a simple repetition of that of the plant, with the addition of a series of new apparatus. The nature of the tissues, the mode of their actions and change — form, division, and destiny of the organs — all these rather teach us that animals of any development are constructed upon an altogether different plan."

Whatever in the above quotation may appear obscure to those to whom physiological ideas are new, will be cleared up, we trust, by what we are about to say on the prominent distinctions between those organic existences which are unequivocally animals, and those which are unequivocally plants, with reference to a basis for the arrangement of the phenomena of vegetable and animal life.

In physiology, the term function is of continual occurrence. What, then, does function signify? Function is the use of a part or organ. The function of the eye is sight; that of the ear, hearing; that of the lungs, the purification of the blood by ventilation; that of the stomach, digestion; that of the liver, to secrete bile. In plants — that of the spongioles of the radicles, to absorb from the soil; that of the leaves, to decompose the carbonic acid of the atmosphere, so as to appropriate the carbon for the uses of the plant; that of the anther, to impregnate the ovule, by means of its secretion, the pollen; that of the ovary, to mature the ovule into a seed.

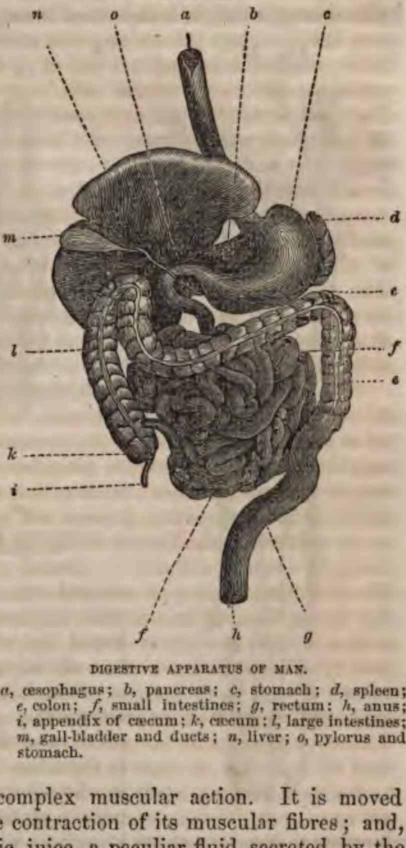
As the functions in all the higher animals and the higher plants are numerous, there is room for method in the arrangement of them. Various methods have been suggested; and, in accordance with some one or other of these arrangements, it has been common to methodize the various topics belonging to physiology.

The kinds of function common to plants and animals, are properly termed vegetative functions—the same which are called vegetable or general organic functions in the quotation from Valentin. The kinds of function, not so obviously possessed by plants, so as to seem peculiar to animals, are named the animal functions.

The vegetative functions are the functions of maintenance; the animal functions are the relative functions, or the functions of relation. The vegetative functions end in the organism of the individual, or, at most, in the organism of the species; the functions of relation establish relations between the animal and the world without.

If we follow the food, in one of the higher animals, from the mouth to its incorporation with the previously existing tissues of the body, the waste of which it is its office to supply, we shall discover what are the more immediate vegetative functions — the same which, by other names, are known as the functions of maintenance; the functions of nutrition; the assimilative functions, or functions of assimilation; and the functions of organic life.

Fig. 22.



DIGESTIVE APPARATUS OF MAN.

a, œsophagus; *b*, pancreas; *c*, stomach; *d*, spleen; *e*, colon; *f*, small intestines; *g*, rectum: *h*, anus; *i*, appendix of cæcum; *k*, cæcum; *l*, large intestines; *m*, gall-bladder and ducts; *n*, liver; *o*, pylorus and stomach.

The food — let it be a piece of meat, or bread — is reduced to a pulp by the movements of the teeth, and the admixture of the saliva, secreted by the salivary glands; it is then swallowed by a somewhat complex muscular action. It is moved about in the stomach by the contraction of its muscular fibres; and, being mixed with the gastric juice, a peculiar fluid secreted by the lining membrane of the stomach, it passes into chyme: this chyme is then, in successive portions, transmitted, by muscular contraction, into the highest part of the intestinal tube, termed the duodenum, which is a kind of second stomach, where the partially assimilated food is first mixed with the bile, and then with the secretion derived from the sweetbread, or pancreas. The mass is now ready to afford chyle, the immediate nourishment of the blood, to the absorbent

vessels, termed lacteals, the extremities of which abut on the lining membrane of the higher parts of the intestinal tube, while the residue is sent downwards by what is termed the peristaltic action of the tube, for evacuation. The chyle, taken up on a very wonderful plan by the lacteal tubes, is transmitted through the singular small organs

FIG. 23.

THE COURSE AND TERMINATION OF THE THORACIC DUCT—*after Wilson.*
2, the aorta; 7, the superior cava; 10, the greater vena azygos, in which, in some mammals, the duct terminates.

FIG. 24.

CHYLE VESSELS.
a, thoracic duct receiving lacteal tubes from *b*, the intestine; *c*, aorta.

termed the mesenteric glands, whence, after important changes, it is again collected by what are named the efferent lacteal tubes; these by degrees unite together into a trunk, which joins the lymphathic vessels coming from the pelvis and the lower parts of the body, to form the thoracic duct *a*, commencing in the abdomen, dividing opposite the middle of the dorsal vertebræ into two branches, which soon reunite, passing behind the arch of the aorta and subclavian artery, and making its turn at *b*, where it receives several lymphatic trunks, terminates at the point of junction of the internal jugular and subclavian veins on the left side of the neck, and into which it pours its contents. The chyle, being thus mixed with the venous blood, is carried with it to the right side

of the heart; and, by the motion of the heart, is thoroughly mingled with that blood; from the right side of the heart the blood, reinforced by the chyle, is transmitted to the lungs, where, by exposure to the air, the venous blood is converted into arterial; the arterial blood, so rendered fit for the nutrition of the body, being sent forth from the left side of the heart, is conveyed by the aorta, the great arterial trunk, and its branches, to the capillary blood-vessels, which pervade all the sensible parts of the body. From these capillary blood-vessels, the several component textures of the living frame attract the new matter, of which they stand in need; while that which is already reduced to the state of debris, re-enters the blood of the capillary system, and returns with the blood, now become venous, to the right side of the heart. The blood, having become impure by the admixture of the debris of the tissues, and from other causes, is purified partly by the lungs, by which a superfluity of carbon is thrown off, while, by the slow combustion which it sustains, animal heat is developed; and partly by the kidney, of which last organ the particular office plainly is to keep the blood free from the various chemical products generated during the successive decompositions which the textures and their first debris undergo.

Such is a rapid sketch of the functions named vegetative in the higher animals, while it indicates the order in which each comes into operation. This sketch also indicates why the epithets nutritive and assimilative, often applied to this order of functions, are not inappropriate; assimilative signifying the making a thing to be of like kind, and bearing reference to the object of these functions being to convert the aliment into a like substance with the body. Thence it appears, also, that the epithet vegetative is rightly applied to this order of functions; because all the obvious functions of plants have the same object, namely, the conversion of their aliments, such as water, carbonic acid, and ammonia, into the vegetable texture. Even in popular language, a person is said to vegetate when he does nothing to withdraw himself from the category of those "fruges consumere nati,"—born to eat and drink.

How inactive soever a person may be, while he vegetates he lives. It is by the exercise of the vegetative functions that life is preserved. As an order of functions they are — some more directly, some less directly — necessary to life. Hence the vegetative functions are sometimes termed the vital functions. But the term vital, as applied to functions, having been used for ages in a restricted sense, should be wholly laid aside. By the older physiologists the term vital was confined to those functions, the uninterrupted exercise of which is indispensable to the life of the higher animals; namely, the circulation of the blood, the respiration, and that part of nervous action which is necessary for the continuance of the circulation of the blood

and the respiration. It is undeniable that these three functions are pre-eminently vital. If any one of these is arrested, even for a very short period of time, the others likewise cease, and immediate death is the consequence. Thus, there are three modes of death readily produced by accident, or disease, corresponding to the three so-called vital functions: death by the heart, death by the lungs, and death by the brain.

While, however, the remaining vegetative functions — Digestion, Secretion, and Excretion, according to the terms longest in use among physiologists—may be interrupted for a time without the loss of life — being not less necessary to life in the main than the three functions just referred to — they are fully entitled to the epithet vital, unless convenience altogether forbade the use of that term.

The vegetative functions, then, are common to plants and animals, in so far as both plants and animals possess functions concerned in nutrition; but the particular functions concerned in that process in plants do not exactly correspond to the special nutritive actions in animals.

There is another order of functions common to plants and animals — namely, the functions of reproduction. These are commonly regarded as distinct from the vegetative functions; although, by taking a somewhat larger view of the term "vegetative," they may be properly included under that name. Thus, if the vegetative functions — namely, the functions of nutrition or assimilation — be held to terminate in the individual, whether plant or animal, then there must be adopted a separate order of functions, under the name of reproductive. But if the larger, and, perhaps, more correct view, be made choice of, that each species is one whole in physiology, having a determinate duration, from the present individuals down to the last survivors, then the reproductive functions, as necessary to the life or continuance of the species, will fall under the same definition as the functions of maintenance in general. According to this view, then, the vegetative functions in plants and animals are the functions during the activity of which the life of a species continues.

The non-vegetative functions are not essential to life; they are present only when the actions of the organic being do not terminate in itself, or in its species. In man, such non-vegetative functions have their highest development. They are the functions by which relations are established between the individual and the world without. Such relations fall under the two heads of relations of knowledge and relations of power, — in general terms, the functions of locomotion and of sense. The same functions in man may be described as the functions of consciousness, including sensation, thought, and volition.

To this statement it need only be added that the vegetative functions correspond to the functions of organic life, while the relative functions are identical with those of animal life.

TABLE OF THE FUNCTIONS IN MAN.

I. — VEGETATIVE FUNCTIONS.

Circulation of the blood............ Respiration........................	Vital, of Old Authors.
Digestion, Absorption.............. Secretion, Excretion...............	Natural, of Old Authors.
Reproduction.......................	Formerly separate.

II. — FUNCTIONS OF RELATION.

Locomotion,	Thought,
Sensation,	Voice.

Such, then, is the ordinary general arrangement of the functions of animals, founded on presumed differences in their essential condition — the first class, requiring for their display only a general property common to all living matter—the latter, some specific properties in addition. There is also another foundation for such an arrangement, in certain general ends, to which more or fewer of the several functions — independently of the individual end to which each is subservient — conjointly conduce. These general ends are three — the ultimate object of every function being either to preserve the individual in a state of life and health, to perpetuate its species, or to maintain its relation with the external world. Of these, the first extend no further than the individual, and have no ulterior end; the second is exercised for the sake, not of the individual, but of the race; and the third furnishes us with the only means which we possess of maintaining an intercourse with each other, with Nature, and with Nature's God. Their consideration is well calculated continually to inculcate upon the mind the main purposes of our existence as living and rational creatures; and to lead us to observe, while investigating the phenomena of each function, the admirable adaptation of the means to the object, not only individual, but general, for which this function was appointed, and to which, in common with others, it conduces, as subservient, directly or indirectly, to the great end of our being.

We pass over the systematic arrangements usually followed in studying the animal and vegetable existences, and which are commonly discussed in physiological works. Such subjects, in our Circle of the Sciences, will fall under the general divisions of Zoology and Botany, where they will be more fully explained than could be possible in a general treatise. We therefore at once proceed to the consideration of

THE ULTIMATE AND PROXIMATE ELEMENTS OF ORGANIC BODIES.

The chemical constitution of Organic Bodies is most readily understood by a reference to what have been named their Ultimate Elements, and their Proximate Elements. The ULTIMATE ELEMENTS are all those substances found in organic matter which rank as simple bodies in modern chemistry; that is, bodies which have hitherto resisted all further analysis. In the whole of nature, chemists admit the existence of no more than sixty-three or sixty-four such simple bodies. Out of these sixty-three or sixty-four elementary substances, seventeen exist in organic nature.

The PROXIMATE ELEMENTS are formed by the union of several of these ultimate elements. Most commonly three or four ultimate elements unite in large proportion, while a few others are present in very minute proportion. The proximate elements, in which there are three principal ultimate constituents, are termed ternary compounds; those containing four are called quaternary compounds. The ultimate elements, which enter in large proportion into the ternary and quaternary proximate elements of organic nature, are the simple constituents of air and water — namely, oxygen, nitrogen, carbon, and hydrogen. As examples of the proximate elements formed out of these, united in different proportions, we may enumerate albumen, well known under the form of white of egg, and caseine, the essential constituent of cheese — what, in short, makes up nearly the whole of well-pressed cheese made from skimmed milk; also the starch extracted from the flour of wheat and sugar; and lignine, which constitutes ninety-five per cent. of wood.

As the proximate elements are made up of ultimate elements, so the solid textures and fluids of organic bodies are composed by the union of the proximate elements. By the union of textures, organs are formed; by the union of organs, the body itself is framed. Here, then, we obtain a mixed analysis of the organic frame, in part chemical, and in part mechanical.

The modern idea of the organs being made up of textures, so that each might be conceived as being reducible to its ultimate mechanical elements, was a happy improvement on the ruder notion of ancient times, which represented the animal body as consisting of flesh, blood, bone, skin, hair, nail, gristle, sinew, nerve, brain, &c. What, then, is a texture? This question is more easily answered by examples than by a definition. The muscular flesh — that is, the lean of beef or mutton — is the muscular texture or tissue; the substance of the brain and nerves is the nervous texture or tissue; the connecting medium of the several organs of the body is the cellular tissue, called also the filamentous, or areolar tissue; and these three are the

best distinguished textures or tissues of the animal body. In the vegetable kingdom, the cellular tissue is almost the only texture.

This kind of mechanical analysis does not admit of a rigid exactness; because it is only in idea, for the most part, that the decomposition can be carried out to a complete mechanical simplicity. Hence, in a practical point of view, we do not define a texture as a simple solid, as if the next act of decompounding would bring us to the proximate chemical elements contained in it, but content ourselves with saying, in the plural number, that the textures are the simpler solids which enter into the structure of complete parts and organs.

This general view being premised, we must now look a little more narrowly — 1st, into the ultimate elements; 2ndly, into the proximate elements; and, 3rdly, into the component textures of organic bodies.

The ultimate elements are divisible into two orders: those which are at once in larger proportion and more constantly present; and those which, while they usually exist in small proportion, follow a more variable rule as to their presence or absence in the several textures. In the first order, as before pointed to, stand Oxygen, Hydrogen Carbon, and Nitrogen. In the second order we find Chlorine, Iodine, Bromine, Fluorine, Sulphur, Phosphorus, Potassium, Sodium, Calcium, Magnesium, Silicium, Iron, and Manganese. In a third order, two or three simple bodies might be placed, which are met with accidentally along with the proper elements of organic matter.

ULTIMATE ELEMENTS OF THE FIRST ORDER.

Oxygen. — This chemical element, when in the isolated state at common temperatures, exists in the form of a gas, with the properties of common atmospheric air, which is indeed oxygen gas diluted, and thereby rendered less energetic in its effects. Oxygen gas is essential to the life of plants and animals; but unless diluted, it destroys both by its excessive stimulus. It supports the combustion of combustible bodies, such as phosphorus, much more vividly than atmospheric air. In combination with other bodies, oxygen exists, diffused extensively throughout the three kingdoms of nature. Besides nearly making a fourth part, by weight, of the atmosphere, it constitutes eight-ninths of the whole weight of the waters of the globe, and not far from one-half of the weight of the common crust of the earth. In the animal kingdom, it forms something less than the fourth part of the weight of dried muscular flesh, and one-half of the weight of lignine, which, as we have seen, is nearly identical with wood. There are, indeed, but few natural bodies at the earth's surface which do not contain oxygen. These are easily

enumerated, — the few bodies which exist in a simple form; carbon as in the state of diamond; sulphur in some of its states; such metals as are found in the virgin state; the combinations of metallic bodies with chlorine, iodine, and sulphur,— for example, the beds of rock-salt, and the sulphurets of iron, copper, and zinc.

The process of combustion, in which oxygen plays so important a part, is not altogether foreign to the subject of Physiology. Combustion is a chemical action, in which the union of one body with another is attended with development of heat, and, under ordinary circumstances, with an evolution of light. When a bit of phosphorus is introduced into a jar of pure oxygen gas at an elevated temperature, the phosphorus unites so rapidly with the oxygen, that vivid combustion is exhibited. What, then, is the source of the heat? To resort to the common explanation, the compound formed has a much less capacity for heat than the oxygen and phosphorus taken together; hence the excess becomes developed or sensible, having been before latent. Or, the explanation may as usefully be drawn from the rule, that when a body passes from a rarer to a denser state of aggregation, as from the gaseous to the liquid or the solid state, heat is uniformly evolved. In the case under consideration, the phosphorus, by uniting with the gaseous oxygen, rapidly condenses it into a solid, in which state the compound exists; and so, in obedience to that rule, much heat is evolved. In most cases of combustion, the temperature of the combustible body must be raised considerably above the common temperature of the atmosphere, by some means independently of the combustion; but as soon as the union between the combustible and the supporter of combustion commences, as between the wick of a lamp charged with oil and the atmosphere, then new heat is developed.

The product of the union of the two bodies in combustion is not always solid, as in the case of phosphorus and pure oxygen gas, more frequently the product is gaseous; thus, when charcoal, a form of carbon, burns, whether in oxygen gas or in atmospheric air, the product is carbonic acid gas—the same gas which is continually discharged from the lungs of animals with the expired air. Nevertheless, heat is evolved in this case,—the oxygen becoming considerably denser by the addition of the carbon. Of late, in the chemistry of the animal kingdom, the term combustion has been extended to include those processes of oxidation which take place slowly within the bodies of animals, accompanied by an evolution of heat; the distinctive name eremacausis, or slow combustion, being employed in this sense. By this eremacausis, not only do the simpler forms of carbon within the animal body become changed by combination with oxygen into carbonic acid, but the salts which contain a vegetable acid, as the acetates, the tartrates, and citrates, pass into carbon-

ates of the same base, just as the tartar of wine (the impure bitartrate of potassa) is changed by a destructive heat into carbonate of potassa, so long known, as derived from this source, by the name of salt of tartar.

Nitrogen.—Nitrogen, like oxygen, exists, at the ordinary temperature of the earth's surface, in the gaseous state, and possesses the common physical properties of atmospheric air. Unlike oxygen, however, it can support neither combustion nor life. It forms nearly four-fifths of the atmosphere by weight, it exists but sparingly in the mineral kingdom, and is not contained, like oxygen, in the common rocks of the crust of the earth. Its chief source in mineral nature, besides the atmosphere, is in two orders of salts, the nitrates and the salts having ammonia for their base. It exists also in the compound mineral inflammables, such as coal, justly regarded as being of vegetable origin. It exists in both the organised kingdoms of nature, yet is much more extensively diffused in the animal than in the vegetable kingdom. Under the head of the nutrition of plants, nitrogen must come in for a large share of attention.

Hydrogen. — Hydrogen is a gaseous body, and the lightest of known ponderable substances. The great source of hydrogen is the waters of the globe, of which it forms one-ninth part by weight. It does not exist in the rocks of the crust of the earth, unless in so far as they contain water. Combined with nitrogen, it is present in ammonia. It makes up about one-sixteenth part of the whole weight in the tissue of wood, and nearly the same in starch and sugar; and of dried muscular flesh it forms about one-thirteenth by weight. In such proportions, then, does the hydrogen of water contribute to the substance of animal and vegetable tissues.

Carbon.—At ordinary temperatures carbon is a solid body; and its most familiar form is the charcoal of wood. Uncombined, it exists very sparingly in the mineral kingdom; but combined with oxygen, in the form of carbonic acid gas, it exists abundantly, as in combination with earthy and metallic bases,—such as the carbonate of lime, the carbonate of magnesia, the carbonate of zinc. The carbonate of lime, as chalk, marble, limestone, marl, is one of the most abundant substances in mineral nature; and of this substance carbon forms one-seventh part by weight. In the atmosphere carbonic acid is uniformly present, but in variable proportion. It exists also in waters. The respiration of animals and the combustion by common fires are continually adding to the carbonic acid of the atmosphere; while the process of vegetation is as constantly decomposing it, appropriating to itself the carbon, and setting free the oxygen. In dried muscular flesh the proportion of carbon by weight is not far from one-half; and in the tissue of wood the weight of carbon is nearly three-sevenths.

ULTIMATE ELEMENTS OF THE SECOND ORDER.

Chlorine.—Chlorine does not exist free in organic nature, but only in combination with metallic bases, or with hydrogen. The chloride of sodium, or common salt, is a constituent of the animal fluids, and in certain classes of animals must be regarded as essential to life, because it is the source of muriatic or hydrochloric acid, the presence of which is one of the conditions of their digestion.

Iodine.—Iodine exists in sea-water, in some mineral waters, and in a few minerals. Its chief source, however, is the oceanic algæ or sea-weeds; it exists also in sponges; and has been detected in the oyster and other marine molluscs.

Bromine.—Bromine exists also in sea-water, and in some mineral waters. It has been found in marine plants, and in the ashes of at least one animal, the janthina violacea, one of the testaceous molluscs.

Fluorine.—Fluorine exists, combined with lime, in the bones and teeth of animals. It has been found also in the vegetable kingdom to a sufficient extent to account for its existence in the animal kingdom. In the mineral kingdom it exists in great abundance.

Sulphur.—Sulphur exists as widely diffused in the mineral kingdom as in volcanic products, also combined with metallic bodies, and in mineral waters; and to these sources in the mineral kingdom should be added the sulphates,—such as the sulphates of lime, as selenite, alabaster, and plaster of Paris; the sulphate of magnesia, or Epsom salts; and the sulphate of baryta, or heavy spar. In the vegetable kingdom sulphur does not exist in much profusion; the sulphates are among the salts met with in the analysis of vegetable tissues; and sulphur is particularly found in some orders of plants, as the cruciferous family and the lichens. In the cruciferous plants—such as the coleworts—the presence of sulphur is indicated by the smell of sulphuretted hydrogen, given off during their decomposition.

Phosphorus.—Phosphorus hardly exists free in any part of nature. The salts which its acid combinations with oxygen form, are widely spread through the three kingdoms of nature, and appear to have important offices assigned to them in the economy of organic life. Phosphorus exists diffused through all fertile soils. The source from which these important constituents of vegetable and animal substances originally reach the soil, is now proved to be the mineral kingdom. The phosphate of lime exists in the mineral kingdom under two forms—namely, apatite and phosphorite—which, though in some districts they constitute even mountain masses, yet are not widely spread over the earth's surface. But recent chemical analysis has satisfactorily shown that minute portions of phosphates

are everywhere spread throughout the earth's surface; so that nothing is easier than to understand, that by the disintegration of these rocks — a process at all times in activity — minute portions of phosphates are continually added to the adjacent soil. Even in sea-water phosphates have been detected. As to the existence of phosphorus in the vegetable kingdom, the ashes of red wheat contain, according to Liebig, 94·44 per cent. of phosphates; the ashes of white wheat, 91·47 per cent.; the ashes of pease, 85·46 per cent.; the ashes of beans, 97·05 per cent. of the same salts; whence it follows that the ashes of these several substances have phosphorus present in them to the extent of 15 to 20 per cent. And as phosphates are invariable constituents of the seeds, not only of all kinds of grasses and leguminous plants, but also of the seeds of plants in general which are fit for food, it is not too much to say, that phosphorus, in minute proportions, is spread throughout the vegetable kingdom.

In the animal kingdom phosphates make a prominent figure among its saline constituents. It has even been believed of late that uncombined phosphorus exists in the animal body, as in albumen and fibrine.

If the phosphates in the human body amount to about one-fifth part of its weight, as indicated by some calculations, then every human body must contain several pounds of phosphorus. The phosphates, and particularly the phosphate of lime, are the chief hard materials of the bones in vertebrated animals, the carbonate of lime being in very inferior proportion. In the true shells, as in those of the crustaceous molluscs, or testaceous animals, there appear to be no phosphates, the hard substance being almost entirely carbonate of lime; but in the true crustaceous animals, as in the shells of the lobster, crab, and crayfish, there is both phosphate of lime and carbonate of lime, the latter predominating. In egg-shells there is a portion of phosphate of lime, while the predominating constituent is the carbonate of lime. The bone, as it is termed, of the cuttle-fish, contains no phosphate of lime. In the zoophytes the composition of the indurated part varies in different animals. Madrepore consists entirely of carbonate of lime, without phosphate; and the red coral yields a little phosphate of lime. In the higher animals phosphates are found generally throughout the fluids and soft parts, as well as in the skeleton.

Silicon, or Silicium. — Silica, or silicic acid, is found in small proportion throughout the organised kingdoms of nature. In the animal kingdom it is met with, in trifling quantity, chiefly in the bones and in the urine. In the vegetable kingdom it performs the important office of imparting strength to the stem, as in grasses, so as to enable them to support the weight of the grain. In the stem

of the equisetacea, or horse-tails, the silica is seen to be disposed in a crystalline arrangement. In the bamboos of the East Indies there occurs a deposit of pure silica in considerable masses, to which the name "Tabashen" is given, and to which various mystical properties are ascribed.

Potassium. — The ashes of trees and of herbaceous plants growing elsewhere than on the sea-shore, contain the carbonate of potassa; and such is the sufficient proof of the existence of potassium generally throughout the vegetable kingdom. The proportion of potassium varies considerably in different plants; and those which contain a large proportion refuse to grow in soils not rich in salts of potassa. The carbonate of potassa was formerly called the vegetable alkali, as if it belonged peculiarly to the vegetable kingdom. But it is now well ascertained, that all the potassa of the vegetable kingdom had its original source in the mineral kingdom, whence, by the disintegration of the rocks containing it in small proportion, new supplies are continually passing into soils.

In the animal kingdom potassium is not found so extensively diffused. Salts of potassa exist in some of the fluids of the human body, as in the blood, the milk, the urine. The same salts are abundant in the urine of herbivorous animals; that is, the excess of potassa received with vegetable food is thrown off by the urine.

Sodium. — In the ashes of sea-weeds, and of plants growing on the sea-shore within reach of sea-water, the carbonate of soda exists. Kelp and barilla are the names applied respectively to the soda obtained from these two sources. Soda was formerly termed the mineral alkali, and perhaps it is more easily obtained from the mineral kingdom than potassa, owing to its salts existing in a more isolated form in that kingdom; for example, the chloride of sodium in the shape of rock-salt and sea-water, the nitrate of soda, and natron, found in certain districts of the globe. Soda, like potassa, exists also diffused through mountain rocks in minute proportion; for example, the difference between felspar and albite, or natron felspar, is, that in the latter the potassa of the felspar is replaced by soda.

Soda is more particularly the alkali of the animal kingdom. Besides the chloride of sodium, widely diffused, as already mentioned, in the animal kingdom, the sulphate of soda, the phosphate of soda, and various combinations of soda with the organic acids, are met with, particularly in the animal fluids.

Calcium. — Lime, or the oxide of calcium, exists widely spread in organised nature. In the vegetable kingdom the salts of lime everywhere exist in minute proportion, while in the animal kingdom these salts accumulate so as to obtain a particular prominence, as has been already indicated under the head of phosphorus.

Magnesium. — Magnesia, or the oxide of magnesium, exists much

more sparingly than lime in organic nature. Phosphate of magnesia is a salt of continual recurrence in the chemical analysis of the parts of vegetables. Thus, in the ashes of wheat, rye, beans, and pease, the phosphate of magnesia exists to a considerable extent. It also occurs in the human blood, and in the bones.

Iron. — Iron appears to possess important offices in organic nature. Its oxide exists, combined with phosphoric acid, in such seeds as wheat, rye, and pease; and the oxide is discoverable in the ashes of various kinds of wood, — for example, in the ashes of fir-wood the oxide has been found to the extent of 22·3 per cent. In the animal kingdom iron is a universal constituent of the blood.

Manganese. — Manganese is found in the analysis of various woods, and also in the human hair.

THE PROXIMATE ELEMENTS OF ORGANIC NATURE.

The proximate elements of organic nature are divisible into the azotised and non-azotised proximate elements; that is, into those which contain nitrogen, and those destitute of nitrogen.

Albumen, fibrine, and caseine are proximate elements, common to both kingdoms. According to a view which has excited much attention, these three proximate elements are merely slightly modified forms of the one proximate element, proteine. Mülder, the author of this view, conceived that the compound to which he gave the name of proteine was the basis of these several substances, and that the difference in their properties depended on the circumstance that the proteine in each was united with a different proportion of sulphur, or, in some cases, of sulphur and phosphorus and salts. A degree of doubt still envelopes this view; but certain it is, that the three proximate elements just enumerated, differing as they do very materially in properties, agree very closely in ultimate composition. All the three, whether obtained from the vegetable or from the animal kingdom, consist of oxygen, hydrogen, carbon, and nitrogen, with a proportion of sulphur and phosphates; the proportion of nitrogen being about fifteen or sixteen per cent.

Albumen. — This proximate element is most conveniently represented by the white of eggs. It is soluble in water, and exists dissolved in the serum, or watery part, of the blood, and in vegetable juices. It is coagulated by heat; that is to say, after having been exposed to the heat indicated by the 160th degree of Fahrenheit's thermometer, it ceases to be soluble in water, and several chemical agents produce the same effect as heat upon it. Albumen exists in the serum of the blood; in the secretions poured into what are termed the shut cavities of the animal body, such as the thorax and abdomen; in the humours of the eye; in the bile; in the muscular tissue; and, more or less modified, in many of the animal solids.

It is met with, also, in many vegetable juices, and in seeds, such as nuts, almonds, &c.

Fibrine. — Like albumen, fibrine is known under two forms — the coagulated and the non-coagulated. The latter is found in fresh-drawn blood and in fresh-drawn vegetable juices; but, on standing, each coagulates. In the coagulated state it exists naturally in muscular flesh, in the gluten of wheat flour, and in the seeds of the grasses.

Caseine. — In milk caseine is found. It does not coagulate spontaneously, like fibrine, nor by heat, like albumen, but by the action of acids it coagulates. Cheese made from skimmed milk, and well pressed, is nearly pure caseine. The name legumine was formerly applied to a substance quite identical with caseine, found in the seeds of eguminous plants. The ashes of caseine are rich in phosphate of lime and in potass. Coagulated caseine is a compound of caseine with the acid employed in the coagulation. When milk, by long standing, seems to coagulate spontaneously, the effect is produced by the previous generation of lactic acid, a portion of which has combined with the caseine. In the oily seeds, such as almonds, nuts, &c., caseine is present, together with albumen.

Gelatine. — Isinglass represents the chemical body termed gelatine, which consists of carbon, hydrogen, nitrogen, oxygen, and sulphur. To speak strictly, it does not exist in the animal tissues, but is formed out of certain of these by the action of boiling water. Gelatine is soluble in hot water, and by cooling forms a jelly. It is precipated by tannic acid, and upon this property depends the formation of leather. The gelatinous tissues, as they are termed, are the bones, the tendons and ligaments, the cellular tissue, or filamentous tissue, and the membranes in general. Glue and size are formed from such tissues by long boiling. Gelatine is found to be more closely allied to albumen, fibrine, and caseine, than was at first supposed. It is believed, however, that it cannot be transformed within the animal body into albumen, fibrine, or caseine; and that is the reason why animals fed exclusively on gelatine die with symptoms of starvation.

Chondrine. — Between gelatine and chondrine, which forms the tissue of cartilage, there is a close resemblance; with this difference, however, that chondrine is not precipitated by tannic acid.

Horny Matter. — Of horny matter there are two varieties, the membranous and the compact. The membranous constitutes the epidermis and the epithelium, or lining membrane of the vessels, the intestines, the pulmonary cells, &c. The compact forms hair, horn, nails, &c. Feathers are allied to horny matter.

Hematosine. — The colour of the blood is due to a peculiar albuminous principle, termed hematosine.

Globuline. — In the blood-globules, besides hematosine, there is another albuminous principle, on which the name globuline has been bestowed.

Kreatine. — There has been obtained of late, from the juice of flesh, a remarkable substance, to which the name kreatine has been given. It is a crystalline compound, consisting of oxygen, hydrogen, carbon, and nitrogen. It has neither acid nor basic properties. It is very soluble in hot water, and cold water retains a minute portion of it in solution. By the action of strong acids it is resolved into a new body, named kreatinine. Kreatine has been found, in minute quantity, in the muscular flesh of the common domestic quadrupeds, and also in that of birds and fishes.

Urea. — The chief peculiar constituent of the urine is urea, which consists of oxygen, hydrogen, carbon, and nitrogen, the last being the predominant element. Although, then, the constituents of urea are the same as those of albumen, fibrine, and caseine, the proportions are very different. In those albuminous bodies the proportion of nitrogen is only about 15 per cent., while in urea it is 47 per cent. In those so-called forms of proteine the carbon amounts to 52 or 53 per cent.: while in urea it is no more than 20 per cent. In the former, the hydrogen is very much the same per cent. as in the latter; but the oxygen in urea is 27 per cent., while in the forms of proteine it is about 22 per cent.

Uric Acid. — In uric acid the proportion of nitrogen is also great, while that of carbon is also considerable. The nitrogen is present to the extent of 32 per cent., while the carbon amounts to 37 per cent. Uric acid is secreted, not only by animals and birds, but also by serpents and many insects. Guano consists chiefly of uric acid combined with ammonia.

Hippuric Acid.—In the urine of graminivorous animals another acid has been discovered, to which the name of hippuric has been given. In this acid there is no more than 8 per cent. of nitrogen.

THE NON-AZOTISED PROXIMATE ELEMENTS OF ORGANIC BODIES.

Oil, or Fat.— For sake of convenience, we still speak of the oily constituents of organic bodies as proximate elements, though, strictly speaking, the oily acids, of which these oils consist, are the true proximate elements. The term fixed oil, or fat, denotes a compound of oxide of glyceryle with certain organic acids, chiefly compounds of that oxide, with stearic, margaric, and oleic acids, — two of these, and often all three, being present. In animals, fat occurs chiefly in the cellular membrane, or in a tissue connected with it. Among plants, oils occur in the seeds, capsules, or pulp surrounding the seeds, and very seldom in the root.

Starch.—Fecula, or starch, as already stated, has only lately been recorded as existing in the animal kingdom. In vegetable nature it is everywhere met with. It occurs abundantly in the seeds of the cerealia; in the tubers of tuberiferous roots, as in the potato; in the stems of palms; and in lichens. Starch, by its ready convertibility into soluble forms—such as dextrine and sugar—is well fitted to act important parts in the economy of vegetable nature. It appears to be stored up in the seeds, roots, and pith of plants, to supply materials for some of the most essential vegetable products.

Gum. — The mucilaginous compound, gum, is widely spread throughout the vegetable kingdom. It is soluble in water, and insoluble in spirit. Its precise uses in the vegetable economy have hardly yet been made known.

Lignine. — The basis of wood, and of the stems and leaves of herbaceous plants, is termed lignine, or woody fibre. It is a fibrous matter, insoluble in all ordinary solvents, and is left after vegetables have been successively exposed to the effects of ether, alcohol, water, diluted acids, and diluted alakalies. Lignine forms about 95 per cent. of baked wood, and is the chief constituent of linen, paper, and cotton. Lignine, together with starch and gum, constitutes the principal mass of the vegetable kingdom.

Such are the chief proximate elements of the organised kingdoms of nature; as to the rest, it would be tedious to enter upon any allusion to them at present, while such of them as deserve particular attention, will meet with the necessary mention in the further course of this treatise.

THE CHIEF COMPONENT TEXTURES OF ORGANIC BODIES.

It will be sufficient to exhibit a few distinct examples of the character and properties of the component textures of organic bodies, without attempting, at this stage of our undertaking, to exhaust the whole of the details which might come under this section.

In the animal kingdom, as before hinted at, there are three well-distinguished textures, namely, the muscular, the nervous, and the filamentous. In the vegetable kingdom there is only one distinct texture, namely, the cellular.

The muscular tissue — to confine our attention to a single fibre — has the property of shortening and elongating itself by a molecular movement of its minute constituent parts, so as to impart a mechanical impulse to the adjacent solids, or fluids. In the meantime the cilia, as they are termed, or the minute bodies observed in motion on membranous surfaces, may be ranked with the muscular texture, though it be still uncertain to what extent the molecular action in each is different. The nervous texture has the property of being so

influenced from without, as to execute and regulate the movements of muscular fibres. The muscular and the nervous textures admit of little modification, retaining nearly the same structural character under all kinds of circumstances. The third texture, the filamentous, being merely the connecting medium of the several component parts, may be regarded as suffering various modifications, or, at least, as representing various other tissues, particularly membrane, bone, and cartilage.

The Muscular Texture.—Two kinds of muscular fibre are known in the animal kingdom, and these, in the higher animals, are well distinguished from each other. One of these occurs in the voluntary muscles, and is named, from conspicuous cross markings, the striped muscular fibre; the other, found in the alimentary canal, the womb, and the bladder, being destitute of such cross markings, is termed the unstriped. In the heart and the gullet both kinds are met with.

FIG. 25.

CONTRACTION OF STRIPED MUSCLE.—*Philos. Trans.* 1840.
Fragment of elementary fibre of an eel partially contracted in water — magnified 300 diameters. *a*, uncontracted part; *b*, the contracted part.

The elementary striped muscular fibres are arranged in sets parallel to each other; the unstriped muscular fibres, on the contrary, cross each other at various angles, and interlace, being arranged like membranous organs enclosing a cavity, which, by their constriction, is contracted.

The striped fibres are usually as long, or nearly as long, as the muscle in which they exist. They vary in diameter from one-sixtieth to one-fifteen-hundredth of an inch; they are of the greatest breadth in crustaceous animals, fishes, and reptiles, and of least breadth in birds. Their average width in the human body is one-fourteen-hundredth of an inch. They are not cylindrical, but more or less flattened. This primitive fibre consists of a great number of primitive particles, or sarcous elements, enclosed in a tubular organ, termed sarcolemma.

The ordinary diameter of the unstriped fibre is from one-two-thousandth to one-three-thousandth part of an inch. It is doubtful if they possess a sarcolemma. The absence of cross stripes seems to arise from a less uniform arrangement of their interior particles, or sarcous elements.

In the lower animals, the distinctive characters of these two kinds of primitive muscular fibre begin to be confounded, especially when the fibres become much reduced in size. The transverse stripes

become irregular, not parallel, and interrupted; and sometimes a fibre shows the transverse stripes near its centre; in short, as the fibres become extremely minute, these anatomical characters are lost; and this may be the reason why in infusory animalcules, the wonderful movements of which they are capable cannot, even with the best microscopes, be referred to the presence of muscular structure.

Each primitive muscular fibre is properly regarded as a distinct organ complete in itself; and there are instances in the animal kingdom of a striped muscle consisting of a single fibre, and this fibre containing only a single file of sarcous elements.

Whenever a primitive muscular fibre preserves a rectilineal direction from end to end, the movement it undergoes is simply rectilinear; but the compound organs, termed muscles, in the human body, and in the larger animals, consist of many thousands of these primitive muscular fibres: still, however, the result must be described as a mechanical traction, compounded of the rectilineal motion, in a number of minute fibres, or parts of fibres, as to length, that original rectilineal motion being the effect of molecular movement of the sarcous elements within the primitive fibres.

These primitive muscular fibres are plainly extravascular; that is, the minute blood-vessels which nourish them and replace their substance, continually reduced to inert chemical products by the exercise of living action, do not enter the fibre, but merely convey the blood to its exterior surface, whence the nutrient matter is attracted into its interior.

Of the nervous filaments supplying the primitive muscular fibre, a like remark may be made as respects all those animals in which nervous filaments can be traced to the component fibres of a muscle. The primitive tubules of a nerve "pass among the fibres of a muscle, and touch the sarcolemma as they pass; but, as far as present researches have informed us, they are entirely precluded by this structure from all contact with the contractible material, and from all immediate intercourse with it." — *Physiological Anatomy*, by Todd and Bowman, p. 161.

Contractility. — The property of a muscular fibre to shorten itself on the application of a stimulus, and, by a quick alternation, again to return to its former length, is contractility. When, then, the contractility of a muscular fibre is spoken of, the term is to be understood in this special sense, or as indicating the quick alternation of shortening and lengthening. In the works of Haller, the greatest of physiologists, this special property of muscular fibre is termed irritability. But as irritability may be sometimes employed in a larger sense, contractility appears to be the more appropriate

term. At the same time, it cannot be denied that irritability includes contractility; that is to say, that contractility of muscular fibre is a species of irritability, and the same thing may be said of excitability. The contractility of a muscular fibre, in the sense here indicated, is a species, or form, of its excitability.

The stimulants which call the contractility of a muscular fibre into activity, are either mechanical, as irritation with a sharp instrument; chemical, like some acid chemical fluid; electrical, like a shock of galvanism; or psychical, like the human volition.

When a muscular fibre, the opposite extremities of which are attached, for example, to adjacent points of two bones, is made to

FIG 26.

BONES OF ARM, HOLDING WEIGHT.

shorten itself forcibly by the application of a stimulus, the more moveable point is drawn nearer to the more fixed point; and this is the great law on which locomotion by muscular fibres depends. Thus the fore-arm is bent upon the arm by a muscle, D, which arises from the top of the latter, and which is inserted at E, at a short distance from the elbow-joint. A very slight contraction will raise the hand, but a considerable increase of power is required to overcome a resisting force.

Tonicity. — There is another form of muscular contraction, which may or may not be the result of the same property, modified by a difference of circumstances. In past times, however, it has been regarded as a different property, and is known by the name of tonicity. The character of this so-called property of the muscular fibre is better taught by examples than by description. If a muscle in the living body be cut right through, each portion, after a few quivers, begins slowly to shorten itself in a permanent manner, so that an empty space is left between the two cut extremities. There being no tendency in these two shortened portions to return to their

former length during an indefinite term, this effect has usually been ascribed to a property different from contractility, under the name of tonicity. Whenever, by any change of the relative natural position of the parts of the skeleton, as by fracture or dislocation, the points to which the opposite ends of a muscle are attached are brought nearer to each other, the muscle becomes permanently shortened by the same so-called tonicity. Again, if the muscles which extend or straighten a joint become paralysed, without a corresponding loss of power in the antagonistic muscles which bend that joint, then the flexor muscles, as they are termed, become shortened by their tonicity, and the joint remains permanently bent. This explains the permanent bent state of the elbow-joints in the paralysis of the upper extremities attendant on the painter's colic, to which all artisans are exposed whose occupations bring them into daily contact with preparations of lead.

Some forms of permanent lock-jaw seem to be of the same character; the muscles closing the jaw, which correspond to flexors, remaining in full vigour, while their antagonists have lost their power.

Muscular Texture. — The muscular flesh constitutes a large proportion of the soft parts of the animal frame. In the higher animals nearly the whole of the muscles are attached to the skeleton, or are skeleton-muscles. In common quadrupeds there is a peculiar subcutaneous muscle — the panniculus carnosus — by which these animals are enabled to move the integuments, so as to shake off from their skin insects and other annoyances. In the human body there is a muscular expansion occupying the neck, corresponding to the subcutaneous muscles in quadrupeds, which anatomists term platysma myoides. The platysma myoides and panniculus carnosus, in higher animals, are conceived to represent an entire system of muscles, which, in its full development, belongs to a different part of the animal kingdom. For example, in the crab and lobster, the muscles which move the limbs are inserted into the shell, which is plainly the integument of these animals, though in them it takes the place of a skeleton. Thus the muscles of locomotion in the crab and lobster are a highly developed system of subcutaneous muscles, corresponding to the platysma and panniculus, or the hypodermal system in mammals, and which, as opposed to the skeleton system of muscles, belongs in general, under its developed state, to all animals, with the exception of the vertebrata. As organs of motion, the ciliary processes, or cilia, might be spoken of with the muscular tissue; but will be referred to elsewhere.

Nervous Texture. — The nervous matter exhibits two forms, the vesicular and the fibrous. The vesicular nervous matter is gray, or

cineritious, in colour, and granular in texture; it contains nucleated nerve-vesicles. The fibrous nervous matter is white and tubular; in some parts, however, it is gray, and its fibres are solid. When both these kinds of nervous matter are united into a variable-shaped body, that body is termed a nervous centre; and the threads of fibrous matter which pass to and from it, are termed nerves. The office of the latter is called "internuncial;" that is, they establish a communication between the several parts of the body and the nervous centre, and between the nervous centre and the several parts of the body.

Of all the solids, the nervous matter comes nearest to the fluid condition. It contains from three-fourths to seven-eighths of its weight of water. In general terms, its chemical analysis may be thus given: albumen, seven parts; fatty matter, five parts; water, eighty parts; while the remainder consists of inorganic matter, the chief of which is phosphorus, if not free, in the state of phosphoric acid.

The fibrous nervous matter is most extensively diffused throughout the animal body. It enters largely into the nervous centres, and is the chief constituent of the nerves, which extend in every direction. Besides the tubular fibre, or nerve-tube, there is also what is termed the gelatinous fibre; the latter is much less abundant, being found chiefly in the great sympathetic nerve. In the tubular fibre, there is externally the tubular membrane, analogous to the sarcolemma of the striped muscular fibre. A white substance, called the white substance of Schwann, forms an interior tube, and within that the material is transparent. The nerve-tubes lie parallel to each other, and never branch. In the cut, *a* represents a nerve tube in water. The delicate line on its exterior indicates the tubular membrane. The dark, double-edged inner one, is the white substance of Schwann, slightly wrinkled. *b* is the same in ether. Several oil-globules have coalesced in the interior, and others have accumulated round the exterior of the tube. The white substance has in part disappeared.

FIG. 27.

NERVE TUBES OF THE EEL, in water and ether—*after Todd and Bowmann.* Magnified 300 diameters.

The vesicular matter exists in the nervous centres; but is never found in nerves. It essentially consists of vesicles or cells, contain-

ing nuclei and nucleoli. The wall of each vesicle is formed of an extremely delicate membrane, containing a soft but tenacious finely granular mass. The prevailing form is globular; but that figure is liable to be changed by packing. There is also a kind of nerve-vesicle, termed caudate, from exhibiting one or two tail-like processes.

A nerve is a leash of nerve-fibres, surrounded and connected by areolar tissue. The areolar tissue surrounding the nerve-fibres is called the neurilemma: from the internal surface of which, processes are sent inwards, to form partitions between the smaller leashes and the individual fibres. The blood-vessels are distributed upon the investing neurilemma and its partition-like processes — and thus the individual nerve-fibre is, like the ultimate fibres of the muscles, extravascular. The nerve-fibres within the sheath lie in simple juxtaposition, the several fibres being parallel to each other. These fibres, which in the cerebro-spinal nerves are chiefly of the tubular kind, while varying considerably, do not exceed the one-fifteen-hundredth of an inch in man and the mammalia.

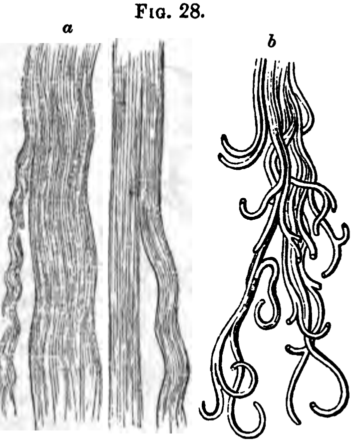
Areolar Tissue, Membranes, &c. — The areolar tissue of recent authorities has a very perplexing number of names. Among the newer names applied to this tissue, is that of filamentous tissue. It is the tela cellulosa, the cellular tissue of the older authorities, called also cellular substance; but, in its ultimate structure, it appears to be of a fibrous character, and hence the term cellular is inappropriate. The areolar tissue is most extensively diffused over the animal body, connecting the other component parts of the frame in such a manner as to allow of a greater or less freedom of motion between them. Owing to this manifest use of the areolar tissue, the additional name "connexive tissue" has been proposed for it. It is placed in the interstices of other textures in greater or less abundance, and in a more or less lax state, according to the exigencies of the case. It everywhere surrounds the blood-vessels, and is hardly absent in parts supplied with blood. In the more solid parts of bone, in teeth, and cartilage, it does not exist, nor scarcely in the substance of the brain, except around the larger blood-vessels. In the muscles it connects the elementary fibres together, yet does not penetrate the sarcolemma, or touch the contractile elements within. It is remarkable, that abundant as it is in the muscles at large, it is in very sparing proportion within the substance of the heart. It exists largely immediately beneath the skin; and hence it is this lax layer of areolar texture which is the seat of the dropsy termed anasarca, and of the occasional accumulation of air termed emphysema.

The areolar texture, moreover, surrounds all the organs, particularly those, like the pharynx, gullet, lumbar colon, bladder, &c.,

which have no free surface. It dips also into the interior of organs, and connects their proper anatomical elements together. It appears, however, that the importance of the areolar tissue in the parenchymatous organs, as they are named — the lungs, the liver, &c. — has been overrated. It always attends the distribution of the blood-vessels in such organs; "but wherever, either from the intricacy of the interlacement of the capillaries with the other essential elements of the particular organ, or the greater strength of these elements themselves, the firm contexture of the whole is provided for, while little or no motion is required between its parts, this interstitial filamentary tissue will be found to be confined to the larger blood-vessels, and to the surface of the natural subdivisions of the organ." — *Todd and Bowman*, p. 87.

Under the microscope, the areolar tissue presents an inextricable interlacement of tortuous and wavy threads, intersecting one another in every direction. Of these threads, there are two kinds, the white fibrous element, and the yellow fibrous element. The threads of the former are inelastic, of unequal thickness, forming bands with the marks of longitudinal creasing, the largest of the bands being often one-three-hundredth part of an inch in width. The threads of the latter are long, single, elastic, branched filaments, disposed to curl when not put upon the stretch, and for the most part about the one-eight-thousandth part of an inch in thickness. They interlace with those of the white fibrous element, but there appears to be no continuity of substance between them. By the crossing in endless succession of these microscopic filaments, and of their fasciculi, there results a most intricate web, the interstices of which are most irregular in size and shape, while all necessarily communicate with one another. These interstices are not cavities possessed of definite limits, since they are, in fact, formed out of a mass of tangled threads. It appears at once, then, that the term cell is inappropriate to these interstices. In certain parts, however, of this texture, secondary

FIG. 28.



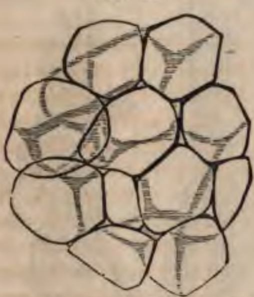
a, white, and *b*, yellow fibrous tissue, *after Todd and Bowman*. Magnified 320 diameters.

cavities, not inappropriately termed cells, occur, particularly in the subcutaneous cellular tissue in which fat accumulates. These secondary cavities, or cells, often visible to the naked eye, have a somewhat determinate shape and size.

The fatty or adipose tissue has the like office of filling up interstices with the areolar tissue; and hence, being found almost constantly associated with that tissue, it has been too commonly regarded by anatomists as merely one of its modifications. The adipose and areolar tissues, however, appear to be altogether distinct and independent. It has, indeed, long been remarked that there are many situations in which areolar tissue uniformly exists in which fat never appears, while there are some situations — for example, in the cancelli of bones — exhibiting a copious deposit of fat, without any vestige of areolar tissue. And as the two tissues seem to be quite distinct, even in those situations where both exist in proximity, the old term adipose cellular tissue should be discarded.

Fat is not to be confounded with adipose tissue. The tissue is the thin membrane, thrown into closed vesicles, or cells; the fat is what these vesicles, or cells, contain. The tissue, or membrane, is about the one-twenty-thousandth part of an inch in thickness, and is quite transparent; it is of the simplest structure, and incapable of further mechanical analysis. Each vesicle is a distinct organ in itself, varying from one-three-hundredth to one-eight-hundredth part of an inch in diameter.

Fig. 29.



FAT VESICLES — *after Todd and Bowman*, assuming the polyhedral form from pressure against one another.

The fat itself is a form of oil, resolvable into stearine, oleine, and margarine.

Fat is extensively diffused through the animal kingdom. It exists not only in perfect insects, but also in the larvæ. It is found in molluscs. In all the tribes of vertebrated animals it is met with. In many fishes it is found only in the liver, — as the cod, the whiting, the haddock, and the rays. In reptiles it exists chiefly in the abdomen. In the frog, toad, &c., it is found in long bands on each side of the spine. In birds it exists chiefly between the peritoneum and the abdominal muscles; also, however, in the bones of the extremities, particularly of the swimming tribes. In mammals generally it abounds, yet with some exceptions; for example, the hare, in which sometimes hardly a particle of fat is discoverable.

In the healthy human fœtus fat accumulates in considerable quantity after the middle of the period of gestation. The quantity of fat in a moderately fat man has been estimated at about one-twentieth of his weight.

The white fibrous tissue and the yellow fibrous tissue are not confined to the areolar texture. The white fibrous, or inelastic fibrous tissue constitutes the ligaments of the joints and skeleton, the tendons of the muscles, and the membranes termed fibrous membranes. The yellow fibrous tissue, or the elastic fibrous tissue forms some structures of great importance in which elasticity is requisite, as in the ligamenta subflava of the spine, and various parts of the mechanism of the larynx and windpipe. A peculiar modification of this texture constitutes the middle or proper coat of the arteries.

Simple membrane, together with epithelium, or epidermis, constitutes the tegumentary surface of the body, internal and external, or the mucous surfaces and the integuments; while an epithelium, spread over expanded cellular tissue, constitutes the serous membranes, or the linings of the shut cavities.

In the higher animals the mucous and serous membranes are well distinguished from each other. The former line the open cavities of the body: one extends in man, for example, from the frontal sinus into the cavities of the nose, ear, and mouth, and descends by the windpipe to line the countless number of minute air-cells; on the other hand, it passes through the gullet to the stomach, and so through the small and great intestines to the extremity of the rectum. The second great mucous membrane may be described as commencing in the pelvis of the kidney; it descends through the ureters to the bladder, and from the urethra, in both sexes, is transmitted into the organs of generation. The first of these great mucous membranes is termed the gastro-pulmonic membrane; the second, the genito-urinary mucous membrane. Owing to the extreme minuteness of the air-cells, which the pulmonic mucous membrane lines, the area of that membrane far exceeds the whole extent of the surface of the body.

The serous membranes line the great shut cavities of the body. The peritoneum, or serous membrane of the abdomen, is the largest membrane of this class. The membrane itself is a shut sac, like a double nightcap. The sac within contains nothing but secretion, the secreting surface being everywhere in contact with itself, that is, with another portion of the same inner surface of the sac; the inner or secreting surface being everywhere free, that is, unattached, while the outer surface is called the surface of attachment, because

it is at every point united by coalescence with adjacent organs or parts.

Besides the peritoneum, or serous membrane of the abdomen, the serous membranes of the human body are,—the pleura, forming two separate shut sacs within the chest; the pericardium, or serous membrane of the heart, often termed fibro-serous, as having a fibrous layer in connection with it; the serous membrane of the brain, the arachnoid membrane; the serous membrane of the testicle, the tunica vaginalis; to which may be added, the synovial membranes, or membranes of the joints, and the bursal membranes, in which the great tendons play.

THE BLOOD IN RED-BLOODED ANIMALS.

By a happy phrase the blood has been described as "circulating flesh," or *chair coulant*. It ranks with the fluids; but the term fluid in Physiology differs widely from its signification in Physics. The blood is water, containing a considerable portion of solid organic matter. Human blood is about five per cent. denser than water; that is, human blood is water charged with about five per cent. of organic solid matter. The heaviest part of the solid matter of the blood consists of what are termed red particles, or the red corpuscles, and these it is possible to separate by filtration from the remaining part of the blood. To succeed in this experiment, however, the blood of an animal must be chosen, in which the blood-corpuscles are considerably larger than in the human blood. In the frog, the blood-corpuscles are four times the size of those in the blood of mammals. If, then, the blood of a frog be placed on a filter of common white filtering paper, a transparent fluid passes through the filter, and the red particles remain on its upper surface. By this experiment the blood is actually divided into the two parts, to which, respectively, physiologists attach a particular value. In the language of modern authorities, the portion which remains on the upper surface of the filter is the vesicular part; that which passes through is the "liquor sanguinis," or blood plasma. The portion which passes through the filter, after a few minutes, begins to coagulate. The coagulum, or clot, gradually contracts with an exudation of watery fluid, by which it remains surrounded. The part which coagulates is fibrine; the liquid part, or what is usually called the serum, being subjected to a temperature considerably short of that of boiling water (160° Fahrenheit,) forms another coagulum, which is found to be albumen, or nearly identical with white of egg. The watery fluid which remains over is called serosity. This serosity contains all the soluble salts of the blood, and nothing else but a little animal matter.

Such, then, is a brief outline of the constituents of the blood; and even in the so-called white-blooded animals, the composition of the blood is very much the same, since the absence of colour depends less on the total deprivation of red particles, than on the small proportion of that constituent being present.

We are now prepared better to understand what happens when blood is drawn from a vein in the human body. After a few minutes, blood so drawn assumes on the surface the appearance of a jelly, from which, after a time, drops of watery fluid here and there begin to ooze out; these drops become more and more numerous, and finally unite, so as to cover the jelly-like surface with a layer of watery fluid. After a short time, the clot, of which the jelly-like surface is the upper part, is so surrounded with the exuded watery fluid, as to be entirely separated, in most cases, from the sides of the vessel. The clot, however, does not always preserve the same degree of consistence. It is sometimes large, soft, and flabby; at other times, small and firm, almost leathery. It consists, as might be anticipated from what has been already stated, of the red particles and fibrine, or that substance which spontaneously coagulates when the blood of a frog has been subjected to filtration. The coagulation, then, of the clot depends on the coagulation of the fibrine which it contains, and not at all on its remaining chief constituents, the colouring corpuscles. When the clot is examined from top to bottom by a perpendicular section, it shows, in most cases, the red colouring matter diffused throughout, yet plainly in larger proportion at the lowest part, to which, owing to their greater weight, they gravitate before the coagulum has acquired sufficient consistence to intercept their progress. The colouring matter near the upper surface is usually of a more intense red colour than that below, owing, doubtless, to the action of the atmospheric air, by which the dark colour of venous blood acquires the vermilion hue of arterial blood. In every case the clot retains within it a portion of serum, or of the watery part of the blood. When the fibrine coagulates more weakly than usual, a larger proportion of this watery part is retained, giving to the clot an unusually soft and flabby consistence. Hence, without taking into account the degree of consistence of the clot, the relative proportion of the clot to the serum cannot be estimated. Of two cases in which the proportions are alike, the clot will be large in that in which the coagulation is weaker, and small in that in which the coagulation is stronger; the apparent quantity of the serum being greater in the latter case, owing to the large proportion of it retained in the clot. When the clot is large, and at the same time very firm, the fibrine is both abundant and highly coagulable.

The surface of the clot is generally quite flat; in other cases it is remarkably concave, or cupped, as it is termed. And when it is

cupped, it is most commonly covered with a more or less thin layer of a yellowish opaque jelly, well known to physicians by the various names of size, buffy coat, and inflammatory crust. This yellow or buff-coloured layer on the surface of the clot, as its last-mentioned name indicates, is regarded by physicians as marking an inflammatory state of the body in the person from whom the blood was drawn. This layer is composed of the fibrine of the blood, separated from the red particles on the surface of the blood just before the clot forms. The unusual tendency to separation between the fibrine and the colouring particles, in cases where the buff is to appear, may be discovered while the whole blood is still fluid, by placing the cup between the eye and the light, when thin films, not unlike oil upon water, of a dark colour, will be seen floating on the surface of the blood. These films are plainly layers of fibrine already separated, through which, owing to their tenuity, in most cases, the dark colour of the venous blood shines. When the buff is to be very thick, these layers of fibrine on the surface of the still fluid blood, being opaque, exhibit their natural yellow colour. At the same time that there is this greater tendency to a separation between the red particles and the particles of fibrine, it has also been observed that the red particles have an unusually great disposition to unite together in the form of rolls, like piles of coins.

The following table exhibits, from recent authorities, the mean relative proportions of the several chief constituents of human blood in the two sexes:—

	Male.	Female.
Water	779	791
Red particles	141	127
Albumen	69·4	70·5
Fibrine	2·2	2·2
Extractive matters and free salts	6·8	7·4
Fatty matters	1·6	1·62

What particularly strikes us on glancing at the table, is the small proportion of fibrine and the large proportion of albumen, notwithstanding that fibrine appears to be the nutrient constituent of which the most important solids of the body stand chiefly in need. Nay, the proportion of fibrine stated in the table is even an exaggeration, since what are termed the colourless blood-corpuscles cannot be sufficiently detached from the fibrine. The large proportion of red corpuscles also creates surprise, since these corpuscles are not directly concerned, as far as is known, in the nutrition of the solids. By far the most abundant solid in mammals, like man, is the muscular flesh. This muscular flesh is almost entirely made up of fibrine, identical, or nearly identical, with that which exists, however sparingly, in the blood. Further, when the animal body is much exercised, the muscular tissue is that which must require the greatest

amount of repair; since it plainly appears that every living act is attended with a chemical decomposition and consequent waste in the organ concerned. It is impossible, then, to suppose that the small proportion of fibrine existing in the blood should be the source of repair to the muscular system. The proportion of fibrine in the blood is no more than one-fifth per cent.; so that, if the whole blood of the body be estimated at twenty-five pounds, the quantity of fibrine will be the one-twentieth of a pound, or something more than five drachms. It will hardly be maintained that the small proportion of fibrine in the blood arises from its unceasing exhaustion by the nutrition of the muscular tissue, for, were this the case, fibrine would increase enormously in the blood, after a few days' complete repose from muscular action.

Is it probable, then, that the albumen of the blood supplies the waste of the muscular tissue by passing into fibrine, when it is attracted from the liquor sanguinis into that tissue? In this supposition there is no difficulty. We have seen that albumen is very nearly identical with fibrine in ultimate composition; and it is certain that the egg, out of which the chick is developed, — that is to say, fibrinous flesh as well as blood, membrane, and bone, — consists of nothing but albumen, a little oil, and some saline matter. Of albumen there is about seven per cent. in the human blood, or in the mass of the circulating blood there is something less than two pounds of albumen. Even this quantity will not suffice to supply the waste of the muscular tissue long, not to speak of the other demands upon it, without being continually renewed by the addition of the products of digestion.

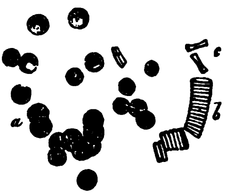
As the proportion of fibrine in the blood is not found to diminish under deficiency of food, it has been conjectured that it is the result rather of the decomposition of the blood itself, or of some of the tissues, than that it is designed to sustain any share in nutrition. But this view is not yet sufficiently matured to permit of being dwelt upon in this place.

The whole subject of the red corpuscles of the blood still presents great difficulties. Many observations have been made upon these bodies throughout the animal kingdom; but the exact use which they serve in the living frame is still a problem. These corpuscles constitute about 14 per cent. of the whole mass of human blood, or there is about twice as much by weight of the red corpuscles in the blood as there is of albumen, and seventy times as much as there is of fibrine.

When a drop of human blood is placed under the microscope, nothing but an opaque mass is seen, owing to the crowded state of the fluid with red corpuscles; but when the drop is diluted with a weak solution of salt or of sugar, each corpuscle is seen detached

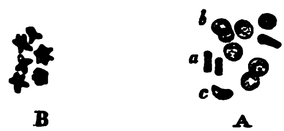
from the rest. The fluid used to dilute the drop of blood must be, as nearly as possible, of the same specific gravity as the serum of

Fig. 30.



RED CORPUSCLES FROM HUMAN BLOOD, magnified 400 diameters—*after Todd and Bowman.*
a, viewed on the surface; *b*, in profile; *c*, aggregation of corpuscles in a roll.

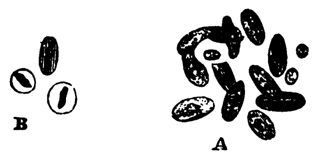
Fig. 31.



RED CORPUSCLES OF THE OX, magnified 400 diameters—*after Todd and Bowman.*
A, in their natural state; B, altered by a menstruum of higher density.

the blood; if plain water is employed, the red corpuscles swell and burst. Each corpuscle is round and flat, like a piece of money; or, to speak more correctly, each corpuscle has the form of a double concave lens, the margin being thick and rounded, and the centre considerably thinner: their size in the human body varies from the three thousandth to the four thousandth part of an inch in diameter. In mammals generally the blood-corpuscles are similar in figure to those in man; but there is a considerable variety of size in different tribes of these animals. They are small in ruminants, in the Napu musk-deer, being no more than the twelve-thousandth part of an inch in diameter. In the camel tribe,

Fig. 32.

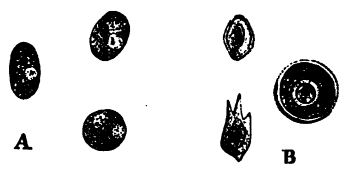


RED CORPUSCLES OF THE PIGEON, magnified 400 diameters — *after Todd and Bowman.*
A, unaltered, with two or three colourless particles; B, treated with acetic acid, which more clearly developes the cell-wall and nucleus.

Fig. 33.

RED CORPUSCLES IN FISHES — *after Wharton Jones.*
a, lamprey; *b*, skate.

Fig. 34.



RED CORPUSCLES OF CRAB — *after Wharton Jones.*
A, three granule cells; B, three nucleated cells.

instead of being round, they are oval, as they are in birds, reptiles, and fishes. In reptiles the blood-corpuscles attain a large size.

In the frog, the red corpuscles consist of a delicate membrane forming a cell, within which is a granular nucleus. The nucleus is globular, and much smaller than the cell; and the space between the inner surface of the cell and the outer surface of the nucleus is filled by fluid, holding the colouring matter in solution. The nucleus cannot be detected in the red corpuscles of the human body, but analogy suggests that its structure must be of the same general character as in the animals, in which these corpuscles are of larger size.

A question has arisen, whether what have been termed the colourless corpuscles of the blood be a distinct set of bodies, or merely the

FIG. 35.

BLOOD CORPUSCLES OF THE FROG, magnified 400 diameters —*after Todd and Bowman.*
a, in serum fully developed; *b*, treated with acetic acid; *c*, colourless corpuscle.

FIG. 36.

PHASES OF THE HUMAN BLOOD-CORPUSCLES—*after Wharton Jones.*
a and *b*, granule cells in the coarsely and finely granulated state; *c* and *d*, nucleated cells; *c*, without colour, and *d*, with colour; *e*, free cellæform nucleus, a perfect red corpuscle.

red corpuscles in a less developed state. The colourless corpuscles are spherical bodies, destitute of colour; they are cells composed of a very delicate membrane, and the cells are nucleated. The addition of weak acetic acid renders the cell-membrane, the nucleus, and the nucleolus more distinct, by dissolving some granules contained within the cells. The colourless corpuscles slightly exceed the size of the red corpuscles in mammals, but not in the other vertebrata. They are thought to be essentially the same as the nucleated particles found in lymph, and in the chyle. They are fewer in number than the coloured corpuscles, being, it is said, in the proportion of one to fifty. In inflammatory states of the blood they become more abundant; and, after great loss of blood, the proportion of these colourless corpuscles is greatly increased. Without entering upon the difficult question, what is the relation between these colourless corpuscles and the red corpuscles, it will be sufficient to say, in the meantime, that the weight of authority is in favour of these two kinds of corpuscles

being identical in species, that is, merely different stages of one organism.

According to this view, then, to quote a passage from Todd and Bowman's *Physiology:* — "In the earliest periods of fœtal life, the blood-corpuscles, as is shown by the researches of Vogt, Kölliker, and Cramer, originate in the same way as the elements of the tissues, from nucleated cells, which are the same, in point of constitution, as the colourless corpuscles; with this exception, that they contain, between the nucleus and cell, a considerable number of granules, which are largest at the earliest periods of embryonic life. At later periods similar nucleated cells are generated in the liver, as first pointed out by Weber, and from these sources supplied to the blood. In this fluid they undergo a transformation into the completely formed blood-corpuscles, by the removal of the granules, the increased development of the nucleus, and the generation of colouring matter, excepting in the mammiferous corpuscles, whose ultimate change seems to consist in the complete absorption of the nucleus, according to Kölliker, or the removal of the wall of the cell, according to Wharton Jones.

"Now, as there can be no doubt that, in the adult, the lymphatic and chyliferous systems afford a source for the constant development of particles identical with the colourless corpuscles, and as such corpuscles are always found in considerable proportion in the blood (being more numerous under circumstances unfavourable to normal changes, as in inflammations), it seems very reasonable to infer that similar transformations of colourless into coloured particles are going on in the adult as in the embryo, and that the lymphatic and lacteal systems must be at least one, and that a fertile source, from which red corpuscles are being continually supplied to the blood." — p. 639.

There is no foundation for the idea that each blood-corpuscle gives origin by a species of reproduction to new blood-corpuscles. The blood-corpuscles probably decay by simple solution, though it does not yet clearly appear what substance in the blood, or in the body, results from their decomposition. The various colouring matters throughout the body have their origin, as is probable, from the colouring matter of the blood.

It is not unreasonable to suppose that the red corpuscles are floating gland-cells, as they are, in all essential points of structure, like the secreting cells of true glands. Their secretion is hæmatine; that is to say, not merely the colouring matter, but the entire contents of the blood-corpuscles, of which iron is probably an essential part, since even the blood of the invertebrate animals contains a sensible quantity of iron, and that when no colour is distinguishable.

Liebig's idea as regards the important function performed by the

red particles, by means of the iron which they contain, must be spoken of when we come to the function of respiration.

Salts of the Blood. — With respect to the saline matters of the blood, the analysis we have given makes the proportion, estimated together with that of extractive matters, no more than about eight parts in the thousand, or somewhat less than one per cent. But, according to other analyses, this part of the blood amounts to more than one and a half per cent. The principal salts of the blood are the albuminate of soda; other alkaline salts, as the carbonate, phosphate, and sulphate of soda, and the chloride of sodium; earthy and metallic salts, as the phosphate of lime, the phosphate of magnesia, the phosphate of iron, the carbonates of lime and magnesia, and the peroxide of iron. In the muscular flesh, which constitutes the chief bulk of the living frame, and that, as before stated, which, from its activity, requires the most frequent repair, there is a considerably less proportion of saline matter than in the blood. Whence it may be inferred that, by the products of digestion, a larger amount of saline matter is thrown into the blood than is required for the nutrition of the chief solids; and therefore, that a great part of the saline matter given off from the blood by the kidney, is merely the excess of what has been received by the blood during digestion, and that it has never entered into the constitution of the living frame.

Some of the salts of the blood are essential to the secretions, particularly to the bile and to the gastric juice.

Waste and Repair.—The continual waste of the constituents of the blood is supplied by the products into which the food received into the stomach is converted. Together with the products of digestion, the contents of the lymphatic vessels, originating in almost every part of the living frame, are poured from the thoracic duct into the circulating system. Perfect chyle is collected from the small organs existing abundantly in the folds of the mesentery, termed mesenteric glands (see page 62), by vessels which gradually unite into a single trunk, by the union of which with the lymphatic trunks, from the pelvis and the lower extremities, the thoracic duct, as already has been shown, is formed. The same general plan pervades the whole of the vertebrate division of the animal kingdom; that is, there is a lymphatic system of vessels pervading the body at large, and a chyliferous system of vessels originating in the intestines, both of which systems unite in a common trunk, which communicates directly with the sanguiferous system. In birds, reptiles, and fishes, however, there are no mesenteric glands. Although it cannot be doubted that important changes take place on such products of digestion as are taken up by the lacteals within the mesenteric glands, it is plain, from the fact just stated, that these

organs are not essential to the formation of perfect chyle; that is to say, a chyle perfectly capable of imparting the required nutritive properties to the blood. One remarkable difference exists between the chyle in mammals, and that in the three remaining divisions of the vertebrata; namely, that in the former it is an opaque fluid, and throughout the latter quite transparent.

Lymph. — There is contained in the lymphatics, and also in the lacteals, when digestion is not going on, the transparent and almost colourless fluid termed lymph. In this lymph there are a number of colourless nucleated cells, which seem, as before hinted at, to be identical with the colourless corpuscles of the blood. In the chyle the same corpuscles are found; but, in addition to these, there is what has been termed the molecular base, a finely granular matter, which varies with the amount of fatty matter in the food. To the presence of this molecular base the milky colour of the chyle is said to be due. To the absence or deficiency of this substance is to be ascribed the transparency of the chyle in birds, reptiles, and fishes. If a dog be fed on food from which fat has been carefully excluded, the chyle is not milky, but whey-like or transparent.

The molecular base is present in the chyle collected at the very origin of the lacteals in the intestinal canal. Both lymph and chyle, when taken from the vessels, undergo spontaneous coagulation. This coagulation depends on the presence of liquid fibrine, as in the blood; while the coagulability bears a close relation to that of the blood in the same animal. The serum of the lymph is an albuminous fluid. Saline matters of the same kind as exist in the blood are found in the serum of the lymph; there is also a trace of fatty matter and of iron. The coagulation of the chyle depends also on the presence of fibrine; and the serum of the chyle contains more albumen and more fat than the serum of the lymph.

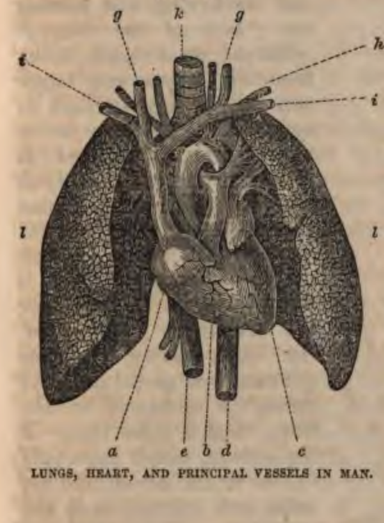
Thus, lymph differs from blood, in having no red corpuscles, and having a less proportion of albumen and fibrine. Chyle differs from blood in the same respects, and also in containing a large proportion of fat, which may amount, it is said, to as much as one and a half per cent. Chyle differs from lymph in containing more albumen and much more fat. Of the fitness of the chyle, derived from the process of digestion, to sustain the nutritive properties of the blood, we have to speak hereafter. One point of difficulty arises, to explain what becomes of the large proportion of fatty matter which it contains. Fat is not a poteine compound; it cannot pass into fibrine, albumen, or caseine — it is a non-azotised principle; but though incapable of contributing to the repair of the more important textures, it is quite capable of supporting animal temperature by the process of slow combustion, termed eremacausis. It seems probable, then, that the superfluity of fatty matter, supplied by the chyle to the blood is

burnt off in the process of respiration, so as essentially to maintain the animal temperature.

What, then, is the use of the lymph which is poured so abundantly into the blood from the thoracic duct? As the lymph contains so many of the constituents of healthy blood, it is impossible to doubt that the addition of the lymph is a source of repair to the blood; but the question remains, What is the source of the lymph? By far the most probable supposition is, that the lymph of the lymphatic system is nothing more than the residue of the liquor sanguinis after the repair of the textures. The lymph is blood, deprived of the whole colouring corpuscles, and of part of its albumen and fibrine. The liquor sanguinis, or blood without the colour ing corpuscles, exudes through the walls of the capillaries, and comes into contact with the ultimate morphological constituents of the tissues, which attract from it what is necessary for their repair; while, by the lymphatics, which are, in fact, a system of veins subsidiary to the red veins, the residue is conveyed to the thoracic duct, to be again mingled with the blood.

From the view now exhibited of the composition of the solids, of the blood, and of the lymph and chyle, we obtain the means of

Fig. 37.



LUNGS, HEART, AND PRINCIPAL VESSELS IN MAN.

Fig. 38.

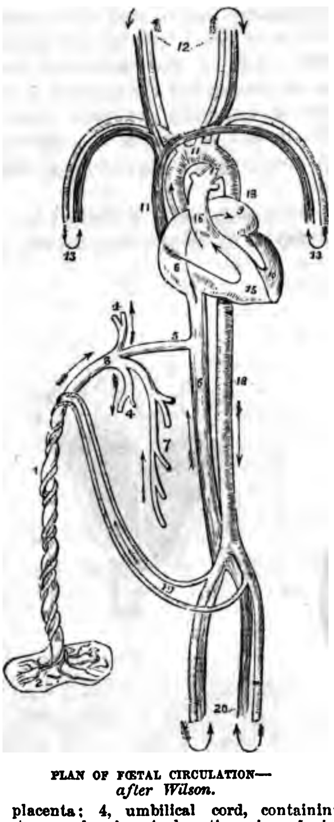
IDEAL SECTION OF THE HEART.

a, right auricle; *b*, right ventricle; *c*, left ventricle; *d*, aorta; *e*, vena cava; *f*, carotid arteries; *g*, jugular veins; *h*, subclavian artery; *i*, subclavian veins; *k*, trachea; *l*, lungs; *m*, left auricle; *n*, pulmonary veins; *o*, pulmonary arteries; *p*, superior and inferior venæ cavæ; *q*, tricuspid valve; *r*, mitral valve; *s*, partition.

judging of the important place held by the blood in the animal economy. The circulation — wonderful as it seems when considered

merely in itself — is yet wholly subordinate in importance to the physiological constitution of the blood. It is a mechanical process, subservient, in certain classes of animals, to the uses of the blood: but the real wonder in physiology is the blood itself — its power of repairing the waste of the solids — and of repairing itself, at the expense of the food, through the medium of absorption. A brief notice, however, of the mechanism of the circulation, in the several orders of animals, must not be omitted.

FIG. 39.



PLAN OF FŒTAL CIRCULATION—*after Wilson.*

2, placenta; 4, umbilical cord, containing artery and vein; 4, hepatic veins; 5, inferior cava; 8, right auricle; 10, left ventricle; 17, ductus arteriosus; 11, aorta.

The annexed diagrams of the circulating apparatus of man, after Carpenter, will enable us better to understand the details which follow. The heart situated between the lungs, in the cavity of the chest, is somewhat conical. The lower end is quite unattached, and points towards the left; during contraction it is tilted forwards, striking the chest between the fifth and sixth ribs, and causing the "beat of the heart;" while the great vessels, rising from the upper and larger extremity, being attached to neighbouring parts, seem to suspend the organ, and to allow its movements freely to take place. The heart in man is a hollow muscle, divided into four cavities, two on either side — the upper of which is termed the auricle, the lower the ventricle — the walls of the latter having, by their contraction, to propel the blood through a system of vessels, being thicker than those of the auricles, which have only to receive the blood from the veins, and transmit it to the ventricles. The circulation of the blood, then, is that process by which the fluid,

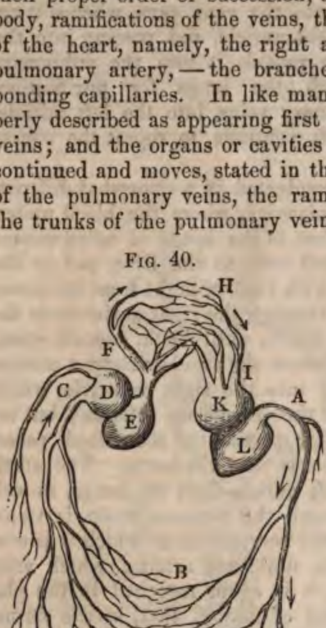
setting out from the left ventricle of the heart, is distributed by the arteries to every part of the body, from whence it passes into the veins, is received from them into the vena cava, whence it returns to the heart, entering the right auricle, and passing into the ventricle on the same side, which propels it into the pulmonary artery, to be distributed through the lungs for purification. Thence it passes, by the pulmonary veins, into the left auricle, which transmits it again to the left ventricle, to repeat the course we have described

The circulation in the fœtus is conducted in a somewhat different manner. Commencing with the placenta, where the blood undergoes some change, analogous to that in the lungs of extra-uterine life, it is conveyed by the umbilical vein to the liver, and to the inferior vena cava; here it mixes with that brought from the lower extremities, and is carried directly through the right auricle into the left auricle by the foramen ovale, which, until birth, remains open, forming a direct communication between the two auricles; a portion only passes from the right auricle into the right ventricle, which contracting, the blood is sent into the pulmonary arteries; but respiration not going on, the greater portion of the blood passes directly through the ductus arteriosus into the aorta. The small portion of blood received by the left auricle from the lungs, as well as the greater portion passed through the foramen ovale, is transmitted into the left ventricle; by the contraction of which it is sent into the aorta, and by means of the umbilical arteries, which arise in the lower part of the abdomen, it is again returned to the placenta. It is a wonderful provision of nature, that, in the fœtus, where the lungs are not called into play, and are nearly solid and impervious, means should be provided to turn from them the great current of the blood — the whole of which, after birth, must pass through them, and to supply them merely with such a quantity as is necessary for their nutrition.

In the first two great divisions of vertebrate animals, mammals and birds, the circulation of the blood, with a few unimportant peculiarities, is performed on one plan. Of this plan, the most characteristic feature is, that the particular circulation through the lungs stands on the same footing as the general circulation over the rest of the body. It follows, from this condition, that no blood-corpuscle can circulate over the body more than once without having previously circulated through the lungs. The circulation, as it takes place in mammals and birds, is conveniently methodised under the two heads of the circulation of the dark-coloured blood, and the circulation of the red-coloured blood. The dark-coloured blood is properly described as appearing first in the venous capillaries, at every vascular point throughout the body. The organs, then, or

cavities in which the dark blood is contained and moves, stated in their proper order of succession, are the venous capillaries over the body, ramifications of the veins, the venous trunks, the right cavities of the heart, namely, the right auricle and the right ventricle, the pulmonary artery, — the branches of that vessel and the corresponding capillaries. In like manner, the red-coloured blood is properly described as appearing first in the capillaries of the pulmonary veins; and the organs or cavities in which the red-coloured blood is continued and moves, stated in their proper order, are the capillaries of the pulmonary veins, the ramifications of the pulmonary veins, the trunks of the pulmonary veins, the left cavities of the heart — namely, the left auricle and the left ventricle — the aorta, or great trunk of the arterial system, the branches of the aorta, and the arterial capillaries. These two separate systems communicate, on the one hand, where the capillaries of the veins of the body join with the capillaries of the aortic system; and, on the other hand, where the capillaries of the pulmonary veins join with the capillaries of the pulmonary artery. The right and left sides of the heart, though in juxtaposition, are wholly distinct organs, and each heart is placed in the middle of its own system; the right being situated in the middle between the veins of the body and the pulmonary artery, and the left heart, between the system of the pulmonary veins and the system of the aorta.

FIG. 40.



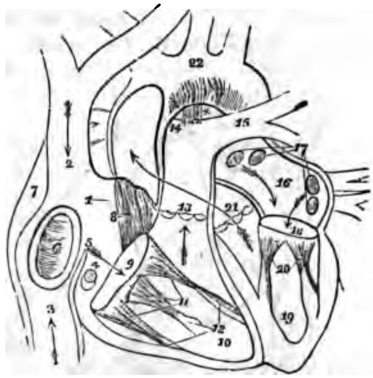
PLAN OF DOUBLE OR WARM-BLOODED CIRCULATION—*after Roget*.
A, aorta; B, system of arteries; C, vena cava; D, right auricle; E, right ventricle; F, pulmonary artery; H, lungs; I, pulmonary veins; K, left auricle; L, left ventricle.

The forces by which the blood is moved in the circulation, are chiefly, if not exclusively, mechanical — the only force of much efficiency being the contraction of the cavities of the heart by a muscular effort, as the blood successively enters each; while valves are so placed as to prevent its movement onwards, except in the proper direction only.

The plan of the circulation in the reptilia is somewhat different; and, though considerable varieties occur in the several orders of this class, one expression may be obtained to represent it throughout. Contrary to what is provided for in mammals and birds, a blood-

corpuscle may circulate more than once over the body without passing through the lungs. The pulmonary artery and the aorta arise from one ventricle, that is, from the only ventricle, so that part of the blood derived from the ventricle passes through the lungs, and part is sent for general circulation over the body. This ventricle receives its blood partly from a systemic, partly from a pulmonic auricle—that is to say, part of the blood is dark colored, and has reached the systemic auricle by the common veins of the body; the other part of the blood is red-coloured, and has reached the pulmonic auricle from the pulmonary veins. Thus, the only organs which contain red-coloured blood in the reptilia, are the pulmonary veins and the pulmonic auricle, while there are two other kinds of blood in the body — namely, the proper dark-coloured blood contained in the veins of the body and the systemic auricle; and the mixture of dark and red-coloured blood first made in the single ventricle, and proceeding from it both to the pulmonary artery and to the aorta.

FIG. 41.

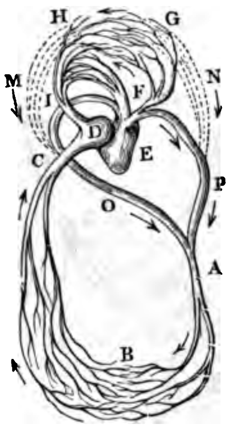


THE ANATOMY OF THE HEART IN SITU—*after Wilson.* Showing its cavities, and tendinous and fleshy chords. The course of the pure blood through the left side of the heart is marked by arrows.

In fishes, the circulation of the blood presents a singular peculiarity. There is but a single heart present — that is, a heart consisting of only two cavities, namely, an auricle and a ventricle, and these cavities correspond, not to the left or systemic heart of mammals and birds, but to their right or pulmonic heart. It is to be remembered that, in fishes, the gills take the place of lungs. Provision is made, in fishes as in mammals, that no blood-corpuscles shall circulate more than once over the body without previously passing through the respiratory organs. Also, in fishes there are but two kinds of blood, the dark-coloured and the red-coloured blood. The cavities containing the dark-coloured blood are the venous capillaries of the body, the venous trunks, the two cavities of the single heart, the branchial artery, its ramifications and capillaries. The cavities containing the red-coloured blood are branchial venous capillaries, the branches formed from them, and the trunk formed in the next succession from them, which is the aorta, or proper artery of

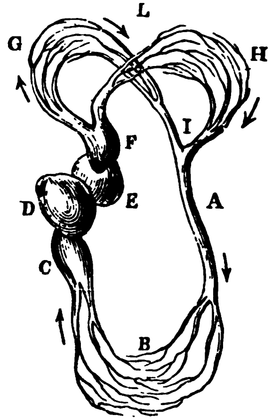
the whole body; lastly, its branches and their capillaries. Thus the peculiarity in fishes is, that the dark blood is sent by the single heart to the gills for purification; and, being re-collected from the gills by capillaries and branches corresponding to the capillaries and branches of pulmonary veins in mammals and birds, passes at once into a trunk which, without returning to the heart, is distributed over the body like the aorta in the two warm-blooded vertebrated classes. This trunk, formed from the branchial venous branches, may be regarded as representing, at once, the pulmonary vein and the aorta.

Fig. 42.



CIRCULATION IN THE BATRACHIA—*after Roget.*
E, ventricle. D, auricle. The aorta and pulmonary artery are seen arising from the ventricle, E, sending branches to the head and neck, and uniting to form a single trunk, A, the descending aorta. The blood is returned by the venous trunks to the auricle, D.

Fig. 43.



CIRCULATION IN FISHES.
D, auricle; C, ventricle; F, branchial artery conveying the blood to the gills, G H, where, being aerated, it is carried by the branchial veins I, which unite unto a single trunk, A, performing the office of an aorta. The blood is returned to the heart by the vena cava, C.

With respect to the circulation of the blood in the inferior classes of the animal kingdom, it will be sufficient to select a few examples, as we shall next proceed to do, without attempting to exhaust the whole subject within the narrow limits to which this treatise must be confined.

Among the molluscs, the circulation of the blood in the cuttle-fish has a remarkably perfect character. In this animal there are three separate hearts at some distance from each other. Each of these, however, has only one cavity. In short, each of the three is a single ventricle. The cuttle-fish breathes by gills. There are only two kinds of blood, the dark-coloured blood and the red-coloured

FIG. 44.

CIRCULATION IN THE CUTTLE-FISH—*after Audouin.*

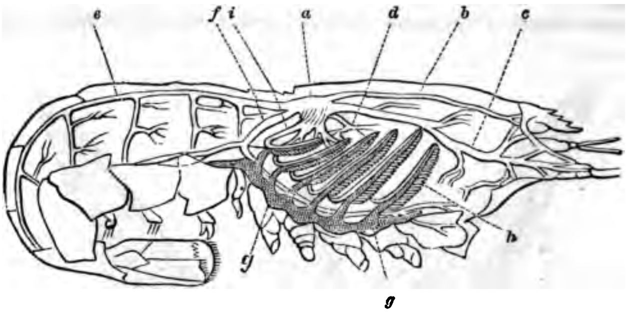
e e, lateral or branchial hearts, conveying the blood to the gills *g g*, whence it is returned to *l*, the central or systemic heart, for general distribution.

blood. The organs which contain the dark-coloured blood are the veins of the body, and the two trunks which they form; the two separate hearts, subservient to the circulation respectively of the two gills; the two branchial arteries and their ramifications. The organs which contain the red-coloured blood are the ramifications and the trunks of the two systems of branchial veins, and the systemic heart, or ventricle, in which these two systems terminate; also the aortic system arising from the systemic heart. The middle, or systemic heart, transmits the red-coloured blood by the aorta and its ramifications all over the body; the blood, having become dark-coloured, is carried from the terminations of the aortic system by the veins of the body in two portions to each of the two lateral or pulmonic hearts; from each lateral heart the blood is propelled to the gills of one side, whence, having become red-coloured, it is carried again to the middle systemic ventricle.

Among the Crustaceans, the circulation of the lobster has been particularly studied. In it the heart has a single cavity or ventricle; and from this heart several large arteries are derived, by which the

blood is conveyed to all parts of the body; but from one of these arterial trunks branches are given off, which proceed to the gills. The blood is brought back from the several parts of the body by

FIG. 45.

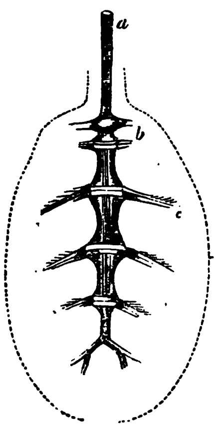


CIRCULATION OF THE LOBSTER.

a, heart; *b* and *c*, arteries of eyes and antennæ; *d*, hepatic artery; *e* and *f*, arteries of thorax and abdomen; *g g*, great venous sinus; *h h*, the gills; *i*, branchial veins.

proper veins, and from the gills by branchial veins; and the blood from these two sources mingles in a common cavity, or sinus, before it re-enters the single ventricle, to be again sent forth. Thus in the lobster there are three kinds of blood,—the red-coloured blood, dark-coloured blood, and the blood composed of the dark and red blood mixed together. The red-coloured blood is contained only in the system of the branchial veins; the dark-coloured blood is contained only in the veins of the body; the mixed blood in the venous sinus, or sinuses, where the two kinds mingle before entering the heart. This mixed blood is contained in the heart and in the arterial or aortic system, and also in the branchial arteries sent off from the aortic system.

FIG. 46.



CIRCULATION IN SPIDERS—*after Carpenter.*

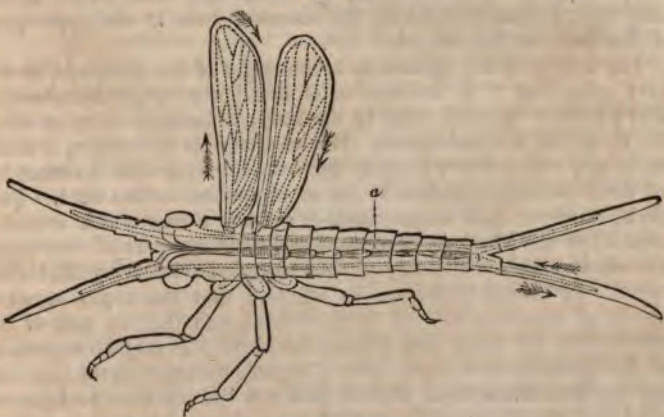
c, large dorsal vessel, or heart; *a*, trunk passing to head; *b*, vessels communicating with respiratory organs.

In the spiders with pulmonary cavities—that is, with pulmonary organs limited to one part of the body—there is an elongated dorsal vessel, which gives off arteries and receives the terminations of veins; the action of which seems to be to drive the blood at once to the several parts of the body, and also to the pulmonary organ. The purified blood from the pulmonary organ must mingle with the blood returning from the several parts of the

body in open spaces, or sinuses, whence, by the branchio-cardiac vessels or veins, it reaches the dorsal heart.

In insects, the circulation of the blood proceeds on a plan altogether peculiar. There is a large dorsal blood-vessel, or heart, provided with apertures and valves, and capable of contraction, but without ramifications, — in short, in insects there is a heart, but no

FIG. 47.



CIRCULATION IN INSECTS.
a, the great dorsal vessel.

blood-vessels; and since the air, by the air-tubes extending from the surface, has access to all parts of the body, there is only one kind of blood, namely, the arterial. The dorsal heart extends nearly the whole length of the insect's body; it is open at the anterior extremity, and by this open part the blood issues to diffuse itself over every part of the body. The contractions of this vessel, or heart, begin at the posterior part, and are propagated forwards, so that the contained fluid is pushed from the tail towards the head. Within the vessel are valves, by which it is divided into compartments, so placed that the fluid can pass forwards, but not from before backwards. The several compartments communicate on each side by lateral slits with the cavity of the belly, and these slits are provided with valves, so that fluids can enter from the belly, but cannot again issue from the vessel otherwise than by the opening in front. The nutritive fluid prepared in the intestine percolates through its walls, and mingles with the blood diffused over the body from the anterior openings of the heart; and this mixture of blood and the product of digestion passes into the heart by the lateral openings.

In some of the Radiata a circulation of the blood is admitted;

but in this part of Physiology there are too many points of controversy to accommodate it to our limits.

On the Renovation of the Blood by Chyle and the other Products of Digestion.—As the blood is unceasingly drawn upon for the repair of the constant waste of the solids and fluids of the body, there is a clear necessity for its continual renovation. Of this renovation the most obvious source is the supply afforded of lymph and the products of digestion, chiefly by the thoracic duct, which, as we have seen, communicates with the venous system at the upper part of the chest, on the left side.

The most probable opinion as to the origin of the lymph is, as we have seen, that it is the residue of the liquor sanguinis, returned after nutrition from all parts of the body, to be again mingled with the torrent of the circulation. But whatever its real origin, it must be, in any event, derived wholly from the blood, so that it cannot be set down as an independent source of renovation to that fluid. The chyle, however, does unquestionably contain matter which is independent of the blood, as never having formed any part of that fluid. The chyle is indeed the only distinct organic fluid bearing that character. It cannot, however, be affirmed that the chyle consists wholly of materials derived from without, and that no part of its constitution has been drawn from the blood. It may be regarded, on just grounds, as a general rule of organic nature, that the nourishing matter obtained from without does not become fit to be incorporated with the living solids, until it has united itself with materials prepared within the organism, and derived from the proper substance of the living agent.

We have already traced the chyle to the food which is received into the stomach. In the healthy body that food undergoes a complete transmutation; and until lately it has been universally believed that the chyle and the feculent matter discharged from the lower bowel are the sole products of that transmutation. Doubts have arisen, on grounds to be stated presently, whether the chyle and the fæces are the sole products of the transmutation of the food in digestion. It is certain, however, that these are at least principal products of that process. However this may be, it is to be remarked that the food is not exclusively the material which undergoes transmutation. The chyle and the fæces are the result, whether exclusively or together with other products of the transmutation, of a mass, consisting of the food, mingled with several remarkable organic agents derived from the blood, such as the saliva, the gastric juice, or the proper secretion of the stomach; the bile, the proper secretion of the liver; and the pancreatic liquor, the proper secretion of the sweetbread.

If the food be exclusively divided between the chyle and the fæces, whatever of the mass of food which does not find its way into

the feculent discharge, must enter into the constitution of the chyle. Thus, from the character of the feculent mass, some notion may be gained of the relation subsisting between the food and the chyle.

By weight the feculent mass discharged in twenty-four hours equals nearly one-sixth part of the average daily quantity of food. The solid part of the discharge amounts to about twenty-seven per cent. of the whole, the rest being water, namely, seventy-three per cent. The twenty-seven per cent. of solid matter may be distributed as follows: — Insoluble matters derived from the food, seven per cent.; insoluble matters derived from the bowels, liver, &c., fourteen per cent.; soluble matters, consisting of bile, albumen, extractive, and salts, six per cent.

Thus, in the fæces, the nutritive proximate elements of organic matter, as already referred to, have almost entirely disappeared; there being nothing of that description in that account, except less than one per cent. of albumen, while the average amount of nutritive matter in the substance of a meal can hardly be estimated at less than fifteen per cent. Two important facts here deserve particular remark,—the small proportion borne by the fæces in weight to the average amount of food, and the minute proportion of nutritive matter which that fraction contains.

Thus, if the chyle and the fæces be the sole products of the transmutation of the alimentary mass in the digestive organs, the chyle must take up nearly all the nutritive matter contained in the food, as well as much of what is not accounted nutritive, together with no small proportion of the matters secreted by the several organs concerned in digestion.

Thus, on the supposition made, if the daily amount of food be estimated at twenty-five ounces, the quantity of chyle which passes daily into the blood must bear a very large proportion to that quantity, and to the nutritive substances, or their products, which that quantity contains.

In estimating the comparative quantities of fæces and chyle, it must not be forgotten that the chyle is more watery, containing about ninety per cent. of water; so that twenty-one ounces of chyle contain no more solid matter than nineteen ounces of fæces. As six or eight ounces of chyle may pass through the thoracic duct in one hour, it is not impossible to believe that from twenty to thirty ounces may pass through that vessel into the blood, in repeated portions, throughout the twenty-four hours. The great quantity of the chyle required to support the common view, hardly tells to its prejudice. But numerous experiments seem to show that true chyle — that is, the fluid found in the lacteal vessels and the thoracic duct, at a certain period after food has been taken, and at no other time — does not contain the chief nutritive parts of the food, or their products;

so that it is forced on the physiologist to consider whether these chief nutritive constituents of the food can make their way into the blood by any other channel.

The transparent fluid found in the lacteals during fasting has very much the same character as the lymph of the lymphatics. The transparent contents of the lacteal vessels, and the contents of the lymphatics, alike coagulate, on standing, into a slightly coherent jelly. This property depends on the presence of fibrine in a fluid form, as in the blood. When white chyle is drawn from the lacteal vessels, or from the thoracic duct, along with the constant transparent contents of these vessels, a coagulation takes place; but this coagulation is plainly due to the coagulation of the transparent fluid, by which certain particles proper to the chyle are entangled. The white chyle itself contains no fibrine; it consists, as it would seem, exclusively of fatty matter in a state of extreme subdivision.

To recapitulate these facts:—

1. There is at all times in the lacteal vessels a fluid exactly similar to what exists in the lymphatics throughout the body.

2. This fluid, common to both kinds of vessels, coagulates, owing to the presence of fibrine.

3. There is no more fibrine in the fluid collected from the lacteal vessels, when they have acquired a white colour after a meal, than when they are colourless.

4. After the longest fasting, there is still found in the lacteal vessels a coagulable transparent fluid, containing the same amount of fibrine as the lymph.

5. If an animal be fed on food from which all fat has been carefully separated, the fluid in the lacteals does not acquire the white colour seen under other circumstances after a meal.

6. When an animal is fed on food free from fat, there is a marked difference in the state of the lacteals, their contents being either wholly or nearly free from the white colour.

It hence appears necessary to assume, contrary to the long received opinion, that there are other products of the transmutation of the food, mingled with the secretions before enumerated, than chyle and the feculent mass, and the next step is to seek positive evidence in favour of such an assumption.

It is undeniable that fibrine, albumen, caseine, and the like, are contained in the food. What, then, has become of these constituents of the food, if they be found neither in the chyle nor in the feculent mass, either in their original form or in a transmuted state?

On this point we shall quote a passage from a work of high authority in Physiology, in preference to expressing this great deviation from the received view in our own words. The passage, however, may require one or two words of previous explanation.

It has already been explained that the whole alimentary canal, from the mouth to the extremity of the rectum, is lined by mucous membrane. On that part of the mucous membrane which forms the lining of the small intestines, and quite peculiar to that portion of the mucous membrane, there are minute processes termed *villi*. These processes are very numerous, giving to far the greater part of the inner surface of the small intestines an appearance like that produced by the pile of velvet. Their length in man is from one-sixtieth to one-forty-fifth of an inch. Each villus is covered by epithelium. The cavity of each villus, besides blood-vessels, contains one or two small lacteals. The villi become turgid during ordinary digestion; the epithelium, which closes each cavity, is either wholly detached, or becomes turgid with the matters passing inwards to the cavity of the villus. After this explanation of the nature of a villus, we cite the passage to which we have referred: —

FIG. 48.

MAGNIFIED SECTION OF THE MUCOUS MEMBRANE OF A DOG—*after Brunner*.

Showing the villi, or absorbing tubes; beneath them the follicles of Lieberkühn, and other coats of the intestines.

"It was evident in these experiments that the marked contrast between the state of the contents of the lacteals, and the condition of the villi, was connected with the presence or absence of fat in the food, and that so long as the food was purely albuminous or fibrinous, or mainly amylaceous, the chyle was transparent, and the villi apparently inactive; but that the addition of fat to the food called the villi into activity, and filled the lacteals with an abundant milky chyle.

"Are we to infer, then, that the lacteals absorb fatty matters only, and that the villi are altogether inactive, save when fatty or oily matters are to be absorbed? We apprehend that such an inference is not justifiable. It may, however, be concluded that the villi and the lacteals are capable of absorbing all substances which the blood-vessels absorb, and by a simple process; but that the absorption of fatty matters devolves upon them only, and is a more complex process, involving considerable changes in their tissue.

"And upon similar grounds we may conclude, that while albu-

minous and fibrinous aliments contribute to the formation of chyle, they do not necessarily undergo the change into chyle in order to be absorbed. But fatty matters appear to admit of absorption in no other way, except by a reduction to the state of molecular base of the white chyle.

"These observations and experiments denote sufficiently clearly that two channels exist for the transmission of the nutritious matters from the intestines to the blood; one through the lacteals to the villi; the other directly through the walls of the blood-vessels themselves. Matters taking the latter route must pass through the liver, and would be subjected to the influence of that gland before they reach the *inferior* vena cava and the right auricle, while those passing through the former channel must permeate a totally distinct system of vessels, namely, the lacteal system, to be conveyed to the *superior* vena cava, and to the right auricle, where, having mingled with the blood coming from the liver, both are transmitted by the right ventricle to the lungs. And it would seem that the object of the two modes of absorption at the intestine, and of the two paths of transmission from the intestine to the centre of the circulation, is to keep separate, up to a certain point, two kinds of material resulting from the digestion of the food. And probably the reason why one kind of product is reserved to pass through the intricate capillary plexuses of the vascular system of the liver, to the exclusion of the other, is because it contains material out of which the liver may elaborate bile, whilst the other material is transmitted through a less complicated series of channels more directly to the lungs."—*Physiological Anatomy*, by Todd and Bowman, p. 591.

It seems impossible, then, to evade the conclusion that the renovation of the blood is not due solely to the supply conveyed to it by the chyle; and that a most important part of that which digestion prepares for the repair of the circulating nutritive fluid is derived directly by absorption from the internal surface of the stomach and intestines. Under this view all the products of the transmutation of the mass of food and the mingled secretions, except the chyle and feculent matter, pass through the circulating system of the liver; since the veins of the stomach, as well as the veins of the intestines, contribute their blood to the contents of the portal vein, which, in its course through the liver, secretes the bile.

When the small amount of the feculent discharge—not exceeding six ounces in twenty-four hours — is compared with the quantity of food received into the stomach in the same period, augmented as it is by admixture with the saliva, the gastric juice, the biliary discharge, and the pancreatic liquor, it is seen that no inconsiderable proportion of new material is transmitted daily from the alimentary canal into the current of the circulation for the renewal of the blood,

and to fit it for the several offices which it has to perform. The aggregate of these several secretions mingled with the food, must far exceed the average weight of the feculent discharge. The quantity of bile alone, secreted in twenty-four hours, must exceed the amount of the feculent discharge. The quantity of bile afforded to the duodenum in twenty-four hours has sometimes been carried far beyond this estimate; for example, to the extent of from seventeen to twenty-four ounces; but more exact observations show that from six to eight ounces come nearer the truth.

Thus, at the most moderate calculation, the blood receives daily a quantity of material for repair equal to the whole weight of the food taken into the stomach. As, however, the secretions with which the food is mingled in digestion, are a direct tax on the blood, it may seem more correct to estimate the daily addition to the blood simply at the weight of food taken into the stomach, diminished by the weight of the feculent matter; so that the average daily addition to the blood by digestion may be taken at from twenty to thirty ounces.

The food, as we have seen, consists of the same chemical elements as the solids of the body and the blood itself; so that the supply of renovation which the system daily receives permits a corresponding loss—let us say of about twenty-five ounces of its substance. This knowledge marks a great era in the progress of Physiology. It is the triumph of the Physiology of our day to have shown the exact accordance between waste and supply in the animal economy; to have shown, on the one hand, the harmony between the chemical composition of the various solids of the body and the chemical composition of the blood; and, on the other hand, the harmony between the chemical composition of the food and the chemical composition of the blood.

A few words are necessary, in addition to what was said in an earlier section of this treatise, on the changes which the food undergoes before it becomes fit to be received into the blood.

The alimentary canal consists of a succession of hollow organs, in which peculiar changes occur. The first change which takes place is the admixture of food with saliva under the act of mastication. The saliva contains less than two per cent. of solid matter, the rest being water. This solid matter consists of organic substances and salts. Part of the organic matter is composed of epithelium which has separated from the mucous membrane of the mouth; the rest is a peculiar matter, to which the name of ptyalin has been given. It is probably nothing more than a species of animal extractive, common to many fluids in living bodies. Among the salts found in the saliva, one deserves particular notice—namely, the sulpho-cyanide of potassium, which gives a red tinge with persalts of iron.

In the stomach the gastric juice effects important changes. This fluid has the property of dissolving flesh and other articles of food out of the body when a proper temperature is preserved; and an infusion of the mucous membrane of the stomach, with the addition of some acid, such as the muriatic acid, has the same effect—a property, although in a slighter degree, also possessed by the mucous membrane of the duodenum, but not by mucous membrane taken from other organs of the body. It has hence been supposed that a peculiar organic principle, to which the name pepsin has been bestowed, exists in the gastric juice, and is the proper agent in these effects; but which, however, has not yet been separated in a distinct form. No mere acidulous solution acts in this manner on aliment. The solution of the chief animal nutritive principles by the gastric juice is so complete, as to create no difficulty in the hypothesis that the dissolved matters may pass at once into the veins of the stomach.

In the duodenum, which is a species of second stomach, the mass which has descended from the stomach, termed chyme, is subjected to the influence of the bile from the liver, and of the pancreatic juice from the sweetbread.

The Bile. — The analysis of the bile has caused much trouble to chemists. It is an animal soap. The peculiar substance which it contains is named bilin. Besides this, there are salts, mucus, and ninety per cent. of water. According to other views, bile is essentially a solution of a salt of soda, formed by combination of the base with two peculiar acids—namely, the cholic acid and the choleic acid; the latter acid containing sulphur.

The following extract from the work already quoted, exhibits an excellent summary of the latest conclusions as to the uses of the bile:—

"1. That it secretes a highly complex fluid, which is poured into the intestinal canal, and there undergoes decomposition. Its colouring-matter (cholepyrrhin, or biliverdin) is carried off in the excrements, and may possibly assist in stimulating the action of the intestine. Its fat is in great part, at least, absorbed by the villi. So much of its fat as is not thus acted upon contributes to form the fæces. Its salts, also, are probably carried off in the fæces. Other of its elements contribute to the digestive process, by promoting the solution in the bowels of some kinds of food which have escaped the solvent action of the gastric fluid. What these elements are, and what kinds of food they serve to dissolve, we have yet accurately to determine; it seems certain, however, that it exercises no solvent power over fatty or oily matters, and probable, that it acts upon azotized matters.

"2. The liver forms sugar and fat by chemical processes in its

circulation, independently of any direct or immediate these substances in the aliments.

"3. The liver is a great emunctory; it eliminates matters, some directly, as the colouring-matter of the bile, which is at once thrown out in the fæces; others indirectly, as fat and sugar, which, passing to other parts of the circulation, are more or less acted on by oxygen and eliminated as carbonic acid and water.

"4. The liver contributes largely to the maintenance of general nutrition; first, by aiding in the solution of certain aliments in the intestinal canal; and secondly, by furnishing food to the calorifacient process."—(*Op. cit.*, p. 606.)

Pancreatic Liquor. — The pancreatic liquid is a colourless limpid fluid, viscid and gluey. It has an alkaline reaction, and is never acid or neutral. It coagulates by heat like white of egg, becoming completely solid. The coagulable principle of the pancreatic liquor resembles albumen, but is not identical with it. The pancreatic liquor, or a piece of the pancreas itself, transforms starch into sugar; and its peculiar property is that of digesting, by a peculiar modification, all the neutral fatty matters met with in the food. When olive oil is mixed with fresh pancreatic juice, and the mixture thoroughly agitated, a perfect emulsion is formed, and a liquid similar to milk or chyle results. No other animal fluid possesses this property. The pancreatic liquor, then, seems designed for the special digestion of oils and fat.

Such, then, are the agencies by which the food is prepared to mingle with the blood for its renovation.

On the Purification of the Blood. — We have seen that the new products supplied to the blood in the process of digestion, take two channels into the venous system—part passing along with the venous blood gathered from all the organs concerned in digestion, to be sent through the liver for the secretion of bile; part passing by the lacteal vessels and the thoracic duct to a vein in the upper part of the chest, so that it is transmitted directly to the right side of the heart, and thence, still along with venous blood, sent through the lungs.

The blood is purified, after the admixture of the new supplies, by the liver and the lungs; hence the liver and the lungs have sometimes been named the Great Emunctories of the blood. A third great emunctory has to be added, namely, the kidney. By these three organs the blood is purified, and rendered fit for the maintenance of the several organs and parts in a state of health.

The Liver.—It is unquestionable that the liver secretes a fluid—namely, the bile — which is of essential service in the process of digestion; but there are, nevertheless, the best grounds for the belief that by the act of preparing this secretion, the liver separates something which, if retained, would prove injurious.

The liver, [illegible] in a rudimentary form in [illegible] development in the [illegible] the cuttle-fish, the snail, the [illegible] very much resembling what [illegible]. In the vertebrated animals [illegible] which it has in man.

In man the liver is a [illegible] gland in the body, and has a very [illegible], a peculiar arrangement of the [illegible] other organs, an artery [illegible] hepatic veins. It is a rule through[illegible] than the corresponding arteries. [illegible] the capacity of the hepatic artery [illegible] by this rule. Why this should [illegible]. The liver has a blood-vessel, to which there is [illegible] in the other organs of the body — a vessel [illegible] venous blood, is distributed like an artery [illegible] of the liver. In the first place, then, it [illegible] of the hepatic veins arises from the [illegible] convey to the great venous trunk of [illegible] transmitted to the liver by the hepatic [illegible] transmitted into it by this peculiar vessel, [illegible] by its ramifications throughout the liver. [illegible] found that the hepatic veins correspond not [illegible] artery, but to the three great arteries which [illegible] without fellows, or not in pairs, but singly [illegible] part of the abdominal aorta. These three arteries [illegible] the bowels, the spleen, the pancreas, and the liver [illegible] proper branches. The veins corresponding to [illegible] of these arteries, instead of proceeding at once to the [illegible] trunk, unite [illegible] the portal vein, or that [illegible] like an artery. [illegible] the bile is secreted, [illegible] up by the minute radicles of the [illegible]

It [illegible] blood of the hepatic artery [illegible] become venous, is poured [illegible] divisions of the portal [illegible]

[illegible] blood of the he[illegible] the portal vein; but [illegible] venous blood pre[illegible] organs concerned in [illegible] produced in the

nutrition of the liver itself and the gall bladder. Thus, as was already stated, the hepatic veins, the radicles of which communicate directly with the minute divisions of the portal vein, return to the great venous trunk of the abdomen all the blood sent out by the three arteries named the cæliac, the superior mesenteric, and the inferior mesenteric.

And this arrangement prevails throughout the order of mammals; while in the rest of the vertebrated orders a vein corresponding to the portal vein is formed by the union of veins derived from the pelvis as well as the abdomen, and supplies the kidneys as well as the liver.

The Lungs and Respiration.—As the liver at once produces a fluid subservient to digestion, and effects a certain purification of the blood, so the lung performs a most important office of purification of the blood, while by that same act it further generates the heat necessary for the maintenance of animal temperature.

It is clearly established by chemical evidence, that whenever carbonic acid is formed by the union of carbon and oxygen, heat is generated. With the air thrown forth in expiration a large proportion of carbonic acid gas is mingled, while the air taken in by inspiration contains no more than a minute proportion of that gas. The organs of respiration, indeed, in all animals, are continually engaged in throwing off from the system carbonic acid gas. During this process of respiration, on the other hand, a quantity of oxygen gas is continually disappearing from the surrounding air. The air which passes into the lung in inspiration contains about twenty per cent. of oxygen; the air which comes forth in expiration contains but a very small proportion of oxygen gas, the place of which is nearly supplied by the carbonic acid gas already spoken of. It has been already shown that a large proportion of carbon exists in the constituents of the body, as well as in the food daily taken into the stomach; hence it is impossible to doubt, when joint reference is made to these several facts, that a slow combustion goes on somewhere within the lung system, by which carbon and oxygen are united into carbonic acid, while, as on every such occasion, heat is produced.

Such, then, is the essential character of the function of re
in the animal kingdom—the purification of the bl
combustion of carbon, while that same combu
animal temperature.

In mammals the mechanism of respiratio
uniform plan. Even in the cetaceous anim
ons consequent on their mode of life har
ing of a subordinate character. In
the function of respiration for the

particularly exemplified. They live in a medium which abstracts heat from the surface in a far more rapid ratio than air, and most of the tribe live in the very coldest seas; nevertheless, their temperature rather exceeds that of man and mammals in general.

The mechanism of respiration in mammals it is not difficult to understand. The lung is an extensible elastic air-bag, enclosed in the cavity of the chest (see p. 95). In that cavity the lung hangs nearly free —that is, the surface of the lung is, with slight exception, simply in contact with the inner wall of the chest, without adhering to that wall. The lung alone communicates with the external atmosphere, there being no passage by which air can penetrate into the cavity of the chest—that is to say, by which it can insinuate itself between the outer surface of the lung or air-bag, and the inner surface of the wall of the chest. The walls of the chest close in above around the windpipe, which is of narrow diameter, ascending from the lung to reach the mouth. By the windpipe the air freely enters every part of the healthy lung. The lung, or bag of air, of necessity fills the actual cavity of the chest, and applies its outer surface close to the lining membrane of the cavity; because, were any part of the lung to collapse, or withdraw itself from the wall, a vacuum would be produced; but such a vacuum is impossible, so long as the lung is everywhere freely extensible, and the air has free access, through the air-tubes connected with the windpipe, to every part of the lung. The lung itself is passive, or nearly passive, in respiration. The chest is capable of alternate expansion and contraction. This alternation of change in the capacity of the chest is produced by muscular contraction, assisted in expiration by the elasticity of certain parts. The expansion of the chest is wholly a muscular act; and its contraction, when moderate, is altogether dependent on the physical properties of its walls. When the chest expands, the lung or air-bag closely follows, being dilated in exact proportion as the chest expands. When the chest contracts its cavity, the lung or air-bag being compressed, still exactly fills the chest, while the superfluous air is thrown out. When the chest expands very slowly, the air

FIG. 49.

AIR-TUBES AND LUNG IN MAN.

b, trachea, or wind-pipe, opening at the back of the mouth by the larynx, *a*; *c*, dissected air passages or bronchial tubes; *d*, lung in its natural state.

may enter as fast as the lung dilates, and then no appreciable rarefaction can take place on the air throughout the air-cells. But when the chest expands rapidly, the air cannot enter by the windpipe fast enough to keep pace with the dilatation of the lung. Why, then, does the lung dilate also in this case? Plainly owing to the universal tendency of air to dilate when previous pressure is diminished. This is an important point in the mechanism of respiration, because this tendency in air to dilate and distend an extensible bag like the lung, counteracts the atmospheric pressure on the external walls of the chest, and much facilitates the further enlargement of the chest. Whenever, then, in inspiration the chest expands somewhat rapidly, the air throughout the lung proportionably expands by its dilatability on the removal of pressure, and therefore becomes rarefied, so that it is no longer equal to the support of the weight of the atmospheric column, which therefore descends by the windpipe, until an equilibrium is restored. Authors frequently term the dilatability of air on the diminution of pressure, elasticity. This is not absolutely incorrect, but it plainly creates confusion. When air is compressed beyond the density at which it exists under the ordinary atmospheric pressure, the recovery of its former volume is properly ascribed to its elasticity. But as conventionally we speak of bodies in general as being solid, liquid, or aëriform, according as they exist in any one of these states under the ordinary atmospheric pressure; so, if elasticity be defined that property by which a body recovers its former volume when compression is removed, we should refer to the expansion of air, when the ordinary atmospheric pressure is diminished, by another term than elasticity, as that implies a term to some condition other than that under which it exists in the circumstances prevailing at the earth's surface.

Fig. 50.

AIR-TUBES AND LUNGS OF BIRDS.
a, trachea; b, pulmonary vessels; c, lung; d, orifice of bronchial tube; e, bronchial tube opened.

In birds respiration is more energetic than in mammals. The temperature of their bodies is somewhat higher — that of mammals being rather below 100° Fahr., while that of birds is often some degrees above that point. The lung or proper air-bag of birds is not larger propor-

tionately than the lung in mammals; moreover it is fixed, hardly dilatable, and does not fill the whole cavity in which it is contained, like the lung of mammals. But in birds the air penetrates to almost every region of the body, and particularly into the abdominal cells, which freely communicate with the divisions of the windpipe. The whole trunk, in short, forms one great respiratory cavity; and when the expanded breast-bone is drawn downwards from the vertebral column, acting like a great bellows, it sucks air into the whole cavity, and by its ascent again expels it. Birds have no proper midriff or diaphragm, by which, in mammals, the chest is closed in below, and divided from the abdominal cavity.

In reptiles the respiration is of a much less energetic character than in mammals and birds. These animals are consequently cold-blooded: that is, their temperature nearly accords with that of the medium in which they live.

The lungs, however, are generally of great size in reptiles, as compared with the bulk of the whole frame. The pulmonary cells are much larger than in mammals and birds, and sometimes the lung degenerates into a mere membranous bag without partitions. As the lining of the minute air cavities in the higher animals is the membrane in which the blood is subjected to the influence of the air, it follows that the smaller the air-cells are the greater is the extent of the tissue in which the blood is exposed to the action of the air; so that, notwithstanding the size of the lungs in reptiles, a much smaller proportionate quantity of blood is brought into contact with the air in a given time than in the higher orders of animals; since they, in the aggregate, have a most extensive lining to the interior of the air-cavities, owing to their very minute subdivision.

In a few reptiles respiration takes place by gills, as in fishes. The Perennibranchiate amphibia, as they are named—of which the Lepidosiren is an example—possess both lungs and gills. The frog in the tadpole state breathes by gills; in the mature state by lungs. In the frog, as in some other reptiles, inspiration is performed on a plan altogether different from what is observed in the higher orders, and the air may be described as being swallowed. The mouth is very capacious. The jaws are first closed, and then the mouth being dilated, the air enters by the nostrils and distends it; then by the compression of powerful muscles, while the nostrils are closed by valves, the air is forced to descend into the lung. It is subsequently expressed, as in the deep expiration of the higher animals, by the action of the abdominal muscles on the chest.

In fishes breathing takes place solely by gills. The water which is impregnated with atmospheric air is taken in by the mouth, and forced out again by the apertures on each side of the neck. It is thus made to pass between the gills, which form a set of comb-like

vascular fringes, supported upon a system of bones termed the branchial arches. These arches are generally four in number on each side, and are attached by one extremity to an intermediate chain of bones situated opposite the middle of the neck, behind the hyoid bone, while by their opposite extremity they are joined by ligaments to the under surface of the skull.

A branchial arch is made up of several pieces joined together by ligaments, the whole being perfectly flexible, and the edges defended by little osseous plates, commonly armed with teeth; and the arches are so placed as to prevent the food taken into the mouth from being forced out through the branchial fissures with the stream of water.

The function of respiration is manifestly the same in fishes as in the higher animals, namely, purification of the blood and the maintenance of animal heat.

Of molluscs the chief part breathe by gills; some however breathe air by organs corresponding to lungs.

The cephalopods, as the cuttle, nautilus, &c., have two gills, one on each side of the muscular sac formed by the cloak. These gills have the form of a compound fern leaf, and are contained within the visceral sac. The water enters through a valvular aperture, and is subsequently expelled with force through the funnel.

Of the gasteropods, the terrestrial species, such as the slug, snail, limpet, and welk, breathe air which is alternately drawn in and expelled from a cavity lined with a vascular network. To these species the name Pulmobranchiata has been given. All of these do not absolutely live on land, but such of them as inhabit the water must frequently rise to the surface for the purpose of breathing.

In the marine gasteropods there are gills variously situated. The situation of the gills in this order has been taken as a principle of arrangement. Thus, in the Nudibranchiata, the gills are naked and placed upon some part of the back; or, as in the Tritonia, along its entire length.

In the Inferobranchiata, the gills resemble two long rows of leaflets placed on the two sides of the body under a projecting edge formed by the mantle.

In the Tectibranchiata, the gills are on one side of the body only, concealed by a flap derived from the mantle.

In the Pectinibranchiata, the gills are placed internally in a large cavity, into which the water is freely admitted, as in all the spiral univalve sea-shells.

In the Conchiferous Molluscs, which include the oyster, mussel, scallop, cockle, solen, &c., the breathing apparatus is elaborately contrived. The gills are in the form of fringes, sometimes termed in the oyster the beard. Every filament of the branchial fringe, by the help of the microscope, is found to be covered with innumerable

cilia, or eyelash-like processes, in constant vibration, thus producing rapid currents in the water, which sweep over the entire surface of the gills, performing the double office of aërating the blood, and carrying towards the mouth the floating animacules or other nutritious particles which may be spread around.

In the Crustaceous animals, such as the lobster, the crab, and the crayfish, there are fringes and tufts variously disposed, which serve the purpose of gills. In the lobster there are pyramidal tufts, consisting of a central stem covered with vascular filaments, in which blood-vessels ramify.

The Arachnidians, or spiders, are divided into two sections, founded on a difference in their mode of respiration. The Trachearean Arachnidians, to which the mites and itch insects belong, breathe as we shall find insects to breathe, by means of air tubes opening upon the surface of the body, by which the air is conveyed to every part of the system. The Pulmonary Arachnidians, of which the true spiders and the scorpion are examples, breathe by lungs, or pulmonary branchia, as they are termed, as combining in some measure the characters of both lungs and gills; their respiratory organ being a bag containing folded laminæ, on which the air, and perhaps sometimes water, acts.

In insects, the air is conveyed by means of air tubes and bags opening on the surface of the body, thus at once aërating the blood, and giving to the frame that lightness necessary for flight through the air.

The bee breathes by respiratory bags, of which it has two, opening on the surface of the body by two holes—stigmata, as they are called—and giving rise to several branched tubes. On the other hand, the respiratory apparatus of the grub of this insect, as indeed of most others, is exclusively tubular; and these tubes have a very different distribution from that which they present in the perfect insect. The same is the case with the caterpillar of the silkworm; but even in the perfect animal the respiratory apparatus, in this instance, is tubular alone. Of these tubes one large one runs along each side of the body, and gives off, opposite to each of the numerous openings upon the surface, two sets of branches, one to the lower part of the body, and the other to the upper, in such a manner that the former branches go chiefly to the muscles moving the feet, and the latter to the dorsal blood-vessel and to the several entrails, which in insects are always situated near their back. The stigmata, or orifices of the respiratory tubes, in the caterpillar of this insect, are furnished with a kind of lips, which open or close them at pleasure; and it is probably, by a similar apparatus, that all terrestrial insects regulate the ingress and egress of air employed in respiration. But some terrestrial insects are capable of respiring even under water, and the

means by which they do this are extremely curious. In general they carry down with them a considerable portion of air in the interstices of the hairs with which their bodies are covered, and which continually exuding an oily fluid prevents the water from coming in contact with it; they breathe, therefore, under these circumstances, in a kind of natural diving-bell. In some insects, however, such as the water scorpion, the air tubes, instead of this contrivance, are provided with long processes extending from the posterior part of the body, the extremities of which, being always above the water, furnish them with a constant supply of fresh air. They are, in fact, a kind of water serpent, or cetaceous animal, in this respect; the bulk of their bodies being under water, while their spiracles, or the holes through which they breathe, are above it. In all insects which fly, it seems to have been the object of nature to carry rather the air to the blood than the blood to the air; and how excellently adapted to this purpose is the tubular and ramified structure of their respiratory apparatus must be sufficiently evident.

In the Myriapoda, such as the multipedes and the centipedes, the air is taken into the body through a series of minute pores or spiracles, placed on each side along the entire length of the animal.

In the Annelida, or red-blooded worms, of which the leech is an example, a series of membranous pouches is provided for respiration, into which narrow ducts open, by which aërated water enters.

In the inferior tribes traces of respiratory organs are still discoverable, though they are so various and so obscure as to render it impossible to comprehend within our limits any particulars of these most rudimentary forms of the function.

The Kidney.—The urinary organs do not occur in the non-vertebrated animals. They appear for the first time in fishes.

The kidneys are voluminous in fishes. They are composed of microscopic tubuli, which terminate in the larger uriniferous tubes, termed ureters.

In some reptiles the kidneys are lobed, and in the higher species have much the same structure as in birds.

In birds the kidney consists of several distinct lobes, connected by the branches of the ureters; and, in many respects, approach nearer and nearer the character of the kidneys in mammals.

The structure of the kidneys in mammals is somewhat complex: the blood from which the secretion is derived is arterial blood. The kidney consists of two substances; the cortical, or outer surface, and the internal, or medullary. Of these the former is the most vascular, and the latter chiefly composed of uriniferous tubes. The blood-vessels undergo a peculiar mode of convolution into minute masses, which are termed "Malpighian bodies." The tubules do not communicate directly with the blood-vessels. The secretion,

Fig. 51.

VERTICAL SECTION OF KIDNEY IN MAN.

Its medullary substance, terminating in uriniferous tubes, opening into the calyx, and passing their secretion into the ureter.

however, first takes place in these tubules, which gradually unite, and finally, under different names, convey the secretion into the canals by which it is transmitted to the bladder.

The urinary secretion is plainly of vast importance in the animal economy. When this secretion is interrupted death speedily takes place; and the kind of death which occurs is regarded as a species of poisoning, owing to the blood becoming contaminated with noxious chemical products, which should have been thrown off by the secretion.

Urea and uric acid are the two most remarkable substances known to exist in the urine. Between four and five hundred grains of urea are thrown off by the kidney from the living system in the adult male. The quantity is considerably less in females, in children, and in old people. The quantity of uric acid thrown off in twenty-four hours is much less, being hardly more than one-thirtieth part of the quantity of urea. Both these substances, as before stated, contain a large proportion of nitrogen. They are products of the disintegration of the solids of the body. The saline matters contained in the urine for the most part have a similar source.

Urine contains about seven per cent. of solid matter to ninety-three per cent. of water. Of this solid matter about three per cent. are urea, one-tenth per cent. uric acid, half per cent. phosphates. As the phosphates exist in the solid parts, one source, at least, of these in the urine is the disintegration of the solids of the body. After very violent and long-continued exercise, the urine is observed to contain an unusual abundance of phosphates. There can be no doubt of the general truth of the proposition that the great purpose of the urinary secretion is to convey out of the system certain chemical products, arising from the disintegration of the living parts, though the precise series of chemical changes which take place be not yet fully determined. A general view, then, of this subject is all that is compatible with the plan of this treatise.

We speak currently of the effete matter of the living system being continually thrown off, and that such a separation is essential to the well-being of the body. It is not remarked, however, that merely slightly altered or exhausted portions of the various tissues, such as bone, cartilage, muscle, tendon, nerve, and blood-vessel, are thrown

off in those processes by which effete matter is got rid of. It has long been noticed that the fluid contained in those vessels, which have been supposed to perform what is termed interstitial absorption, is homogeneous, and that it never shows signs of having been derived from the disintegration of any such solids as those above enumerated. Hence it was always concluded, in former times, that these absorbent vessels had not only the property of taking up the effete matter at the points where it formed, but that they had also the property of decomposing such effete matters, and of converting them into such a homogeneous fluid as is found in the absorbent vessels. It seems now, however, very doubtful if these absorbent vessels take up anything else but liquids; since it is far more probable that the process by which solid parts are absorbed, consists, first, of a chemical decomposition of the solid, under the influence of the oxygen, conveyed to all parts of the system by the arterial blood, by which it is reduced to a soluble form, and then of its transmission through the coats of the minute veins into the blood. Thus the saline matters, such as the phosphates contained in the portion of solid living substance disintegrated, becomes at once mingled with the blood; while the organic tissues, as consisting of oxygen, hydrogen, carbon, and nitrogen, are converted into water, carbonic acid, urea, and uric acid.

We may judge of the extent to which this conversion goes on from the continued renewal of the blood and the solids of the body, which, while the same weight is retained, cannot take place without a corresponding removal of such parts as, by the progress of development to maturity, have reached the stage of decay and disintegration. The component parts of the living solids plainly undergo changes analogous to the growth, the maturity, the decay and death of the whole body. The new portions of nutriment supplied by the blood, in its successive circulations, correspond, at first, to the embryonic development of a young individual. By degrees these parts advance to maturity, and begin, after a short period of efficient service, to lose the energy of their vitality; so that they are now ready to become the prey of the ordinary chemical affinities of their component elements, and, under the action of the oxygen conveyed by the arterial blood, they become again reduced to matter but one degree removed from the inertness of the dust of the earth.

Of the Sap of Vegetables. — The proper sap of plants undoubtedly corresponds to the blood of animals. By proper sap, however, we are to understand not the ascending but the descending sap — that which, after its ascent from the roots, has undergone an elaboration in the leaves, so as to be prepared to afford to the several tissues a new supply of their proper substance.

The crude or ascending sap is totally different from the elaborated

sap. For example, the crude sap of a plant, when flowing upwards in abundance, may afford a refreshing drink, though, after elaboration in the leaves, it may become of a poisonous nature. The *Euphorbia canariensis* is the plant which affords the resin euphorbium of the shops, formerly employed as a blistering substance. This plant the inhabitants of the Canary Islands are said to tap, and draw off the ascending current for the purpose of refreshment, notwithstanding the acrid character of the sap after elaboration.

The descending or elaborated sap abounds in globules, and often, after being withdrawn from the plant, undergoes a species of coagulation. This sap—the proper juice or blood of the plant—plainly contains the materials of the solid parts which compose the structure of the plant, as well as those which enter into its various secretions and excretions.

What, then, is the foundation of the difference between the elaborated or descending sap, and the ascending or crude sap? In the first place it is evident that crude sap does not contain all the materials which, by a certain transformation, may be converted into the constituents of the perfect sap. Whence, then, are those new materials obtained, which, being added to those of the crude-sap, explains the development of the perfect sap? It is plainly the office of the leaves to add those new materials.

It has been a prevalent idea that the leaves of plants correspond to the lungs of animals, and that their use is merely to ventilate or purify the crude sap, as the lungs do the venous blood of animals. A more exact scrutiny of the office of the leaves shows that they are the channel by which a most important part of the food is conveyed into the substance of the plant.

Although carbonic acid is continually given off by certain parts of plants, it is proved, beyond all doubt, that this generation of carbonic acid amounts to but a very small deduction to be made from the far more extensive decomposition of that gas, which takes place in the leaves of plants under the influence of light. The carbon derived from this decomposition of carbonic acid becomes fixed in the plant, while free oxygen is given off. Thus the leaves in reality correspond to the digestive organs of animals, since, though nourishment is derived from other sources, yet a most important part enters by this channel; and it even appears that some other parts of the food of plants enter by the leaves, besides the carbon.

The food of plants consists of water, carbonic acid gas, ammonia, and some saline matters; and these several articles of food enter partly by the spongioles of the radicles, and partly by the leaves. The crude or ascending sap is derived from the spongioles of the radicles, and doubtless contains all the saline and earthy matters which enter into the constitution of the plants; it appears, also, to

contain portions of the other aliments, particularly the watery part and the ammonia. By the additions made to this sap derived from the spongioles, the sap becomes matured, and prepared for the general nutrition of the tissues, and the supply of the secretions. It comes now to contain fecula, gum, sugar, lignin, and also the proteine compounds, albumen, fibrine, caseine, &c., or substances readily convertible into these, by which the annual additions to the stem are made, the fruit is developed, and the several peculiar secretions, such as oil, fixed or volatile, resin, gum-resin, balsam, camphor, and the like, are supplied. And after the sap has served these uses, there is a surplus of nutritive matter left, which is laid up for the supply of the wants of the vegetable economy in the subsequent year; for, obscure as this subject still is, it seems certain that the sap which first rises from the soil in spring becomes mingled with organic products formed in the previous year, by the aid of which, before the leaves have commenced their office, various important effects in the vegetable economy are accomplished; and this is in accordance with a rule of organic nature already referred to, namely, that for materials from without to become fit to be incorporated with pre-existing organic tissues, a mixture with the products of living action is a usual preliminary.

The respiration of plants, like the respiration of animals, consists in the evolution of carbonic acid, and the consequent development of temperature. By this evolution of carbon, which appears to take place at all times, though in minute proportion, some purification of the proper sap must be effected; and there also appears to be other means of excretion, by which the same end is still further promoted.

Of Reproduction. — The continual renovation of the tissues composing the frame of an adult animal, and of the leaves of trees in each successive spring, bears a striking analogy to the reproduction of species by the individual, whether animal or plant.

A germ separates from the body of the parent, which, under the application of certain conditions, different in different divisions of organic nature, becomes developed into a new individual.

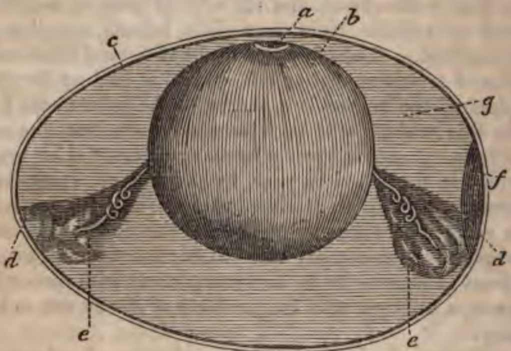
The whole process is of the most wonderful character from beginning to end, and in whatever part of organic nature it is studied. The least complicated mode of reproduction is found in such organisms as the red snow (*protococcus nivalis*,) which consists of a simple aggregation of vesicles, without any definite arrangement, — sometimes united, but capable of existing separately. In simple organisms of this kind, mere rupture gives independent existence to the rudiments of new individuals contained within them.

The successive development of the several structures belonging to the mature individual in the higher parts of both kingdoms, is not less wonderful than the varied primitive development of the germs.

The progress of the development of the chick during incubation affords one of the most interesting examples of this ulterior stage of reproduction.

Let us briefly review the anatomy of the egg at the commencement of the incubation. Beneath the shell there is a membrane

FIG. 52.



SECTION OF A BIRD'S EGG.

a, cicatricula; *b*, yolk-bag; *c*, membrane lining the shell; *d*, attachment of chalazæ, *f*, air space; *g*, albumen.

consisting of two layers, which, by their separation at the larger end, form a space filled with air, especially rich in oxygen, this air vesicle being destined to serve for respiration. Within the inner layer of this membrane lies the white, and within the white, enclosed in its proper membrane, the yolk. From each extremity of the yolk-bag proceeds into the white a knotty body, terminating in a flocculent extremity. These two bodies are termed the *chalazæ*, and their effect is to keep the yolk uppermost in the white; for by shaking an egg violently, the connexion of these with the white is destroyed, the yolk sinking to whatever end of the shell is downwards; and this is the secret of making an egg stand upon end, without proceeding to the violent expedient reported to have been employed by Columbus. On the surface of the yolk-bag is a small round milk-white spot, called the cicatricula, surrounded by one or more whitish concentric circles. The cicatricula is the blastoderm, or germinal membrane, from which the future being is developed. Beneath the germinal membrane there is a canal, which leads to a chamber in the centre of the yolk, and which is filled with a whitish granular substance. Such is the description of the egg in the fowl, and in its general character it represents the matured ovum in vertebrate animals.

As soon as incubation commences, the germinal membrane becomes distinctly separate from the yolk and yolk-bag, spreading and assuming the form of a central pellucid spot, surrounded by a broad dark ring. At the same time it becomes thickened and prominent, and is soon separable into three layers; of these the exterior is a serous layer, the internal a mucous layer, and between the two is situated a vascular layer in which vessels soon become apparent. From the first, all the serous structures of the future animal are developed, as from the mucous layer are all the mucous structures, and from the middle all the vascular structures.

Towards the close of the first day, the serous or outer layer has become thickened into the first rudiment of the dorsal portion of the future embryo, while the two other layers still remain unaltered. At the commencement of the second day, the anterior portion of the embryo is dilated, and the three membranes which represent it have become bent down. At the conclusion of the second day, this inflection is carried still farther, and in the vascular layer a beating point, the *punctum saliens*, the first appearance of a heart, has become developed. On the third day, the serous membrane has become reflected over the back of the fœtus; at one extremity investing the head with a serous covering, and at the other extremity investing the tail. This reflection of the serous membrane is finally to form the amnion or inner lining of the bag in which the fœtus is to be contained.

Fig. 53.

EMBRYO OF BIRD.
With the vessels of the vascular area, after three days' incubation.

The mucous layer, or that next the yolk, at this time lines the open space which is to form the abdominal cavity, and by its inflections gives origin to the rudiments of the abdominal viscera.

The heart in the vascular layer is now seen to be composed of two chambers; and further, the branchial arteries are discovered which join to form the aorta.

On the fifth day, the outlines of the viscera are tolerably distinct, the sac of the amnion is completed, and the liver and lungs begin to appear; the bag of the allantois is well developed. The heart is still that of a fish, and the aorta formed by the branchial arches,

which had been visible from the third day. The successive changes which take place on the vascular system are rather complex. Thus, of five pairs of vascular branchial arches, which at first by their union formed the aorta, as in fishes, those of the first pair on both sides, and of the fifth on the left side, speedily disappear. The third on each side becomes the brachio-cephalic trunks; the fourth of the right side becomes the descending aorta; while the fifth of the right side, and the fourth of the left side, are converted into the pulmonary arteries. The very short trunk common to the two pulmonary arteries, and also the equally short trunk of the aorta, are produced by the tranformation of the single cavity of the original "bulbus arterosus" into two distinct canals; and thus this wonderful metamorphosis is completed.—*The General Structure of the Animal Kingdom*, by Jones, p. 627.

Fig. 54.

e, Formation of the digestive cavity; e, embryo; f, layers of germinal membrane; h, heart; s, stomach.

About five days from the commencement of incubation, the vascular layer of the germinal membrane has spread extensively over the yolk; and as the vessels are formed, they are found to converge towards the navel of the embryo, and to constitute a distinct system of arteries and veins communicating with the aorta and the heart of the fœtus, and forming a vascular circle surrounding the yolk. These vessels are termed omphalo-mesenteric vessels. The omphalo-mesenteric arteries arise from the mesenteric arteries, and the omphalo-mesenteric veins return to the vena cava of the chick.

When the intestinal system has reached some degree of development, a communication is found to have arisen between the yolk and the intestine, by a wide duct termed the vitello-intestinal duct, and by which the nutritive substance of the yolk enters the alimentary canal for the alimentation of the embryo. By the time incubation is completed, the yolk-bag is empty, and the place of the duct is marked merely by a little cæcal appendage.

Fig. 55.

FORMATION OF THE ALLANTOIS.
e, e, embryo; g, layers of germinal membrane; s, stomach; i, allantois.

The allantoid membrane first makes its appearance in the early part of incubation, while the abdomen is still open, as a delicate bag derived from the anterior part of the rectum, but it quickly enlarges, so as at last to line nearly the whole extent of the membrane of the shell;

and being thus exposed to the air, which penetrates the shell, it becomes an important organ of respiration. When fully developed, it is copiously supplied with arteries and veins. The arteries derived from the common iliac trunks correspond to the umbilical arteries in mammals, and the veins corresponding to the umbilical veins, reach the inferior vena cava.

About the nineteenth day of incubation, the air-vessel at the large extremity of the egg is ruptured, the lungs begin to breathe the air which it contained, and the vessels of the allantois become by degrees obliterated. On the twenty-first day the chick escapes from the shell, to begin a new phase of life.

On the fourth day the chick is about four lines in length; on the sixth day it is seven lines; and then what appear to be voluntary motions are first observed. Ossification commences on the ninth day, and on the fourteenth day the feathers appear; and if taken out of the egg, the chick can open its mouth.

Reproduction in the Vegetable Kingdom. — The first stage of reproduction in the vegetable kingdom is the maturation of the seed; the second stage the germination of the seed, by which a new living plant is produced.

The seed is matured, as a general rule, within the inferior portion of the pistil or female organ, termed sometimes germen, sometimes ovary—the latter term being most used. This inferior portion of the pistil becomes, by maturation, the fruit or seed-vessel, called also the pericarp. Familiar examples of the pericarp are the cherry, the apple, the pear, the poppy-head, the flat pouches of garden honesty, and of shepherd's purse, the French bean, and the pea-pod.

If we examine the several flowers in which these pericarps form, we shall find all of them are mere enlargements of the base of the pistil—that is, of the germen or ovary.

If the interior of the germen or ovary be examined at an early period, the rudiments of the seed are found to be already present in the form of minute membranes not yet closed in on every side. The condition requisite for the perfect development of these rudimentary parts into perfect seeds is the entrance into their interior of a pollen granule derived from the male organ or stamen. The upper part of the stamen, named anther, secretes the pollen, which, being transferred to the upper part of the pistil, there finds entrance, and descends through the middle part or stile into the cavity of the germen or ovary, and finally into the cavity of the rudiment of the seed. Forthwith the seed becomes developed into a perfect part.

The perfect seed contains, beneath its exterior membranes, a part destined to be developed into the stem, another part destined to be developed into the root, and other parts destined to supply nourishment up to the period when the new individual has attained sufficient development to draw the means of support from the soil and

from the atmosphere. The nourishment contained in the substance of seeds is starch.

The conditions necessary for the development of a seed into a new plant are the presence of moisture, warmth, and atmospheric air. When put into the earth, not far from the surface, the seed swells by the agency of moisture, and imbibes oxygen from the air diffused through the water of the soil. In proportion as it acquires oxygen, it throws off carbonic acid. The starch during this process is, in part at least, changed to sugar, or to a soluble substance more readily conveyed onwards, as the stem and radicle are developed. Besides starch, the seed contains certain saline bodies, such as phosphates, and the other mineral constituents found in organic bodies, which serve for a supply till the root is sufficiently developed to draw such constituents from the soil.

Under the influences of these sources of supply, the gammule, or part of the seed representing the stem, at last rises above the ground, and the radicle, or part representing the root, descends into the earth. The parts of the seed destined to supply nourishment are the seed-lobes, or cotyledonary bodies, and the albumen; the latter being present only in certain orders of seeds. When the albumen is absent, the cotyledonary bodies are proportionally larger. In many plants these seed-lobes, cr cotyledonary bodies, rise above ground in the form of temporary leaves, and plainly perform for a time the office of leaves, by drawing nourishment from the atmosphere. But as the proper leaves form on the stem, the cotyledonary bodies, whether they ascend into the atmosphere or remain below ground, shrivel and decay; and the same thing happens to the albumen when it is present.

When this stage is attained, the growth of the new individual proceeds on much the same plan as in mature plants.

Recapitulation.—Such, then, is an outline of organic life in the two great departments of nature endowed with vitality; and a brief review of the connexions of these two kingdoms of nature with each other, and of their common dependence on mineral nature, will form a proper conclusion to this section of our treatise.

We have seen that the elements which compose the animal kingdom exist in the mineral kingdom. The original position of these elements is in the rocks composing the crust of the earth, and in the water which rests on its surface, or in its gaseous envelope, the atmosphere. The next position in which these elements are found, previously to their becoming part of the substance of the bodies of animals, is in the component parts of the vegetable kingdom—namely, in parts of vegetables which serve for food to animals, such as the roots of the potato, the turnip, the carrot, the parsnip, the onion, the leek, the beet, the leaves of the various species of brassica, spinach, parsley, lettuce, the seeds of wheat, barley, oats, and

Indian corn, rice, and the like. We next find these elements advanced to the rank of constituents of an animal body, and sometimes passing from one animal body to another. The next transition of these elements is a return to the mineral state; not, indeed, for the most part to resume their original form, if that were the component parts of a rock, but to enter into the soil, or to join the waters of the surface, or to float in the air till received again into the vegetable kingdom, to perform the same round as before.

For example, one of the ores of manganese, which when exposed to heat gives off oxygen abundantly, occurs in the oldest strata of the crust of the earth. Thus, an atom of oxygen which has lain fixed in a rock for an incalculable number of ages, may have been set free only a year or two ago, and yet if the history of its progress could be traced, it would fill a volume.

Its first condition, after being set free from its imprisonment, is a particle freely floating in the atmosphere. We may suppose, then, that it descends to the earth absorbed in a drop of rain. It unites with a minute portion of carbon existing in the soil, to form carbonic acid, which, being taken up by the root of some useless weed, is conveyed to a leaf, and then again set free,—its companion, the carbon, being retained. We may next suppose that amid a thunderstorm, as it floats high in the air, it is yoked to an atom of hydrogen, to form an atom of water, and that it again descends to the earth; now not as an impregnation but as a minute integral portion of a drop of rain. It is again taken up, we will suppose, by the radicle of such a grass as the common poa or meadow grass, and the atom of water being decomposed, it becomes fixed in a minute portion of albumen within the leaf of the grass. By-and-by this grass is cropped by a cow grazing in the pasture; and the albumen being soon changed to caseine, it comes forth as a constituent of milk. It is quickly found in a human stomach undergoing the process of digestion, and being received into the blood circulates there, to escape, perhaps, from its new possessor by a cut of the finger.

The blood left exposed to the air quickly putrefies, and our atom of oxygen escapes from the fibrine or albumen in which it existed, in company again with carbon, or in the form of carbonic acid. It probably soon comes into contact with a leaf, for example a spinach leaf, and the carbon being disjoined from it and fixed in the plant, our atom again becomes free. It now, for the first time, becomes the victim of respiration, being drawn into the lungs of a passer-by. Being conveyed over his body with the arterial blood, after passing through his heart, it is quickly found uniting with the debris of the muscular fibres which have been longest in action; and, returning in the venous blood to the lung, united with a portion of carbon, is thrown out as a part of the expired air, in the shape of carbonic acid. It is now carried high into the air, and falling into

the southward current, is quickly found journeying westward, with the trade-wind, at a lower level and in a warmer region. As it reaches the luxuriant vegetation of the West Indian Islands, it is speedily disjoined from its associated carbon, and again set free, leaving its companion to form part of the substance of a luxuriant banana. Soaring again in the air, it forms part of the northern current, and in no long time is again found fit to assist the respiration of the inhabitants of the same region from which a short time before it had departed in company with a particle of carbon.

Such is a slight specimen of the unceasing changes which the particles composing organic nature undergo. There is a circulation of particles from the mineral kingdom through the vegetable to the animal kingdom; and the air which the animal kingdom contaminates the vegetable kingdom purifies. Lastly, the surplus of contaminated air, which the limited vegetation of temperate countries cannot purify, is wafted to feel the influence of a tropical vegetation, and brought back restored to the required state of purity for animal existence.

With the following passage from Liebig, one of the greatest names in organic chemistry, we shall close our account of the vegetative functions:—"When the vegetable kingdom, in the temperate and cold zones, ceases to decompose the carbonic acid generated by the processes of respiration and combustion, the proper, constant, and inexhaustible sources of oxygen gas are the tropics and warm climates, where a sky, seldom clouded, permits the glowing rays of the sun to shine upon an immeasurably luxuriant vegetation. In our winter, when artificial warmth must replace deficient heat of the sun, carbonic acid is produced in superabundance, and is expended in the nourishment of tropical plants. The great stream of air which is occasioned by the heating of the equatorial regions, and by the revolution of the earth, carries with it, in its passage to the equator, the carbonic acid generated during our winters; and in its return to the polar regions brings with it the oxygen produced by the tropical vegetation."

The Locomotion of Animals.—The next subject for our consideration is that function by which living beings are enabled to move from place to place. Among the lowest orders of animal existences, as in some zoophytes and mollusca, we find those which are permanently stationary, and, like plants, unable to leave the substance to which they are attached. And even some of these which do move about, as the sea-blubber, the sea-pen, and many others, do so passively; and, like the duckweed and star-grass among plants, are moved in water chiefly by the currents, and tides, and winds; but the number of those in whom locomotion is otherwise than active, is certainly very small. Again, during one period of their existence, the fixed zoophytes do possess a power of locomotion. Thus the

young sponge, after its separation from the parent stem, for several days swims about as if to find the appropriate spot to which it may attach itself; while the cilia, or arm-like appendages, to the action of which its locomotive powers are due, fade and disappear, as if no longer required, after the animal has attached itself to the rock. Similar properties are found among the polypes lodged in the madrepores and corals, with which all are familiar. In the hydra, a species of polype inhabiting our fresh waters, for the knowledge of which we are indebted to M. Trembley, of Geneva, we find an early example of locomotive powers curious in the extreme. If the animal is introduced into a glass, it may be seen, as in the figure,

Fig. 56.

LOCOMOTION OF HYDRA VIRIDIS—*after Trembley.*

when standing erect slowly to bend its body, until its mouth touches the surface of the vessel; its foot is then detached, and brought towards the head, which is then projected forwards, and the process repeated, until a desirable position is obtained. We will pass over the Infusoria, so named from their being found in all animal or vegetable infusions, after being kept a sufficient time; since they are all microscopic, and not to be seen by the naked eye. Their movements are very rapid; and the microscope reveals, as is familiar to most persons, a strange and busily-moving mob even in a drop of water. Among the Medusæ some are remarkable for their organs of locomotion, being furnished with an apparatus not unlike the fins of a fish, with which they strike the water vertically, and give an ascending impulse to their bodies. Among the molluscs, the motions of the snail are familiar to every one. They are effected by what is called its foot, or a mass of muscular fibre, situated on the strong membrane which contains the entrails, and also attached to the shell. It glides along the surface, partly by forming a vacuum by means of this organ, and partly by a viscid mucilage secreted by the part. It is thus, also, that some bivalve molluscs, as the common cockle, mussels, razor shell fish, and others, progress — the animal protruding its foot beyond the shell, and crawling along upon it; and it is furnished also with the same kind of adhesive mucilage, for the purpose not only of steadying its steps during motion, but also, as drawn out into threads under the name of byssus, of preventing it, when at rest, from being washed away, by tides and currents, from the rocks to which it attaches itself.

Advancing in this great class, we find some animals, as the cuttle, moving by a kind of arms or tentacula attached to their head, and employed as oars, or as feet, when moving along the bottom of the sea. On account of the singular place of attachment of the feet, the animals of this, the highest order of molluscs, are called Cephalopods (Gr. *kephale*, head, and *pous*, foot). With the exception of the pearly nautilus (*Nautilus pompilius*), which has many tentacular organs attached to the head, all other cephalopods have eight arms; to which, in some kinds, as, *e. g.*, the calamary and sepia, two long and slender tentacula are added, which can be retracted into sheaths. Both the eight ordinary arms and the two tentacles are provided with suckers, by which the animal can attach itself at pleasure. The paper nautilus (*Argonauta*), has but eight feet, and one pair of these expand at their extremities into broad and thin membranes; the fabled use of which has afforded a beautiful subject of poetic imagery in all ages; but similar appendages occur in *Octopus violaceus*, and in *Octopus velifer*, in which both the first and second pairs of feet support broad and thin membranes at their extremities. Now, neither of these species inhabit a shell in which the expanded membranes could be used to waft the animal along the surface of the ocean, as has been said or sung of the Argonaut, from Aristotle to Cuvier, and from Callimachus to Byron.

The comparative anatomist, who has devoted most attention to the structure and economy of the class of Cephalopods, has concluded that —"the physiologist, in contemplating the structure of the velated arms, is compelled to deny them the power of being maintained erect and expanded to meet the breeze. What their real function may be is still to be determined; but the removal of the erroneous impressions entertained on the subject is the first step towards the attainment of truth."* Since the article from which the above passage is quoted was published, it has been shown that the membranous arms of the argonaut are the organs for secreting and repairing the shell. This function of the supposed sails of the paper nautilus has been determined by the experiments, instituted, at the suggestion of Professor Owen, by Madame Power, at Messina in Sicily. One of the "sails" was cut off in several living specimens; the right sail being removed in some, the left in others; and the creatures were then kept in a submarine cage, and supplied with food. Some of them survived the operation four months, when it was found that the shell had grown only on that side on which the membranous arm had been preserved. By these and other observations it has been finally determined, not only that the argonaut is the veritable constructor of the beautiful and delicate shell which it inhabits; but that its expanded membranous arms never act as sails to catch the wind. While the Glaucus, a beautiful little mollusc, of the Indian seas and Mediterranean, painted in blue and silver, swims with great swiftness by its conical and oar-like appendages.

* See Professor Owen's Article, "Cephalopoda," Cyclopædia of Anat. and Physiol., vol. i., (1836), p. 527.

Passing now to the Annelida, we find the earth-worm progressing by means of setæ, or bristles, attached to the skin, which the animal fixes on the ground, while, by the elongation of the rings which encircle the body, it moves onwards. Then the head is applied and fixed to the ground, and the body, by the contraction of its rings, drawn towards it. In the Nereis we find numerous tentacula as organs of locomotion, by which, and by undulating inflexions of the body, the animal swims with great rapidity; while the leech, independently

FIG. 58.

GLAUCUS FOSTERI.

FIG. 59.

THE LEECH (HIRUDO OFFICINALIS.)

of its power of swimming by ordinary vermiform motion, is furnished with an apparatus for suction at either extremity of its body. By fixing, alternately, one or the other, and drawing its body towards it, the animal advances at pleasure.

The motion of insects is much more perfect than that of any of the preceding classes, while a calcareous or horny covering gives attachment to muscles of great power, and enables individuals to move with immense force and velocity. All spiders dart upon their prey with great rapidity, while some species possess the power of conveying themselves to considerable distances by means of threads, which, propelled from their bodies, they cling to, and are wafted upon them by the winds. The crabs move with great rapidity on the ground; but, from the construction of their

FIG. 60.

FIG. 61.

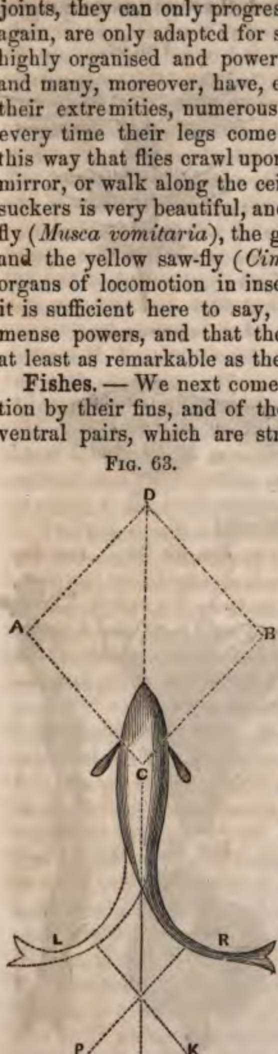
FIG. 62.

60. Suckers of Blue-bottle Fly.
61. " Yellow-Saw Fly.
62. " Great Water Beetle.

joints, they can only progress sideways. The lobsters and cray-fish, again, are only adapted for swimming; but the muscles of both are highly organised and powerful. All winged insects have six legs; and many, moreover, have, either in the course of their legs, or at their extremities, numerous suckers, by which they form a vacuum every time their legs come in contact with any surface. It is in this way that flies crawl upon a perpendicular surface, or on a smooth mirror, or walk along the ceiling of a room. The structure of these suckers is very beautiful, and is best seen in the common blue-bottle fly (*Musca vomitaria*), the great water beetle (*Ditiscus marginalis*), and the yellow saw-fly (*Cimex Lutta*). But the most remarkable organs of locomotion in insects are their wings. Of these, however, it is sufficient here to say, that they are moved by muscles of immense powers, and that the velocity with which they are moved is at least as remarkable as the force.

Fishes. — We next come to fishes, most of whom effect locomotion by their fins, and of these they employ chiefly the pectoral and ventral pairs, which are strictly analogous to the upper and lower extremities of the superior tribes of animals. Some fishes effect their progression by the motion not of the fins but of the spine; as the lamprey, which has neither pectoral nor ventral fins, and which seems to move in its natural element, the mud, entirely by the lateral flexion of its spine, which it first draws into an S-like curve, and then shoots forward the anterior portion. The same is the case, also, with the eel, when it creeps on land. Others again, as most flat fishes, which, like the lamprey, have neither pectoral nor ventral fins, use their tails principally in making progress in the water. This operation is extremely simple. Everybody knows that the ordinary way of propelling forwards a boat is by rowing; that is to say, by means of one or more pairs of oars passed over its sides, the action of which is exactly similar to the pectoral fins of fishes. But it is likewise well known that a boat may be, with equal certainty, urged forwards by what is called sculling; that is to say, by means of one oar passed over its stern, and continually

Fig. 63.



MOTION OF FISHES.

moved in the water from side to side. Now, it is precisely upon this latter principle that the tail of fishes, moving from side to side, operates in propelling them forward. It is evident that the oar on the one hand, and the tail on the other, in this alternate lateral motion, is continually displacing a quantity of water great in proportion to the length of the instrument employed, and consequently to the sweep which it makes in its oscillation; and it is by the resistance which the water makes to this displacement, by the oar or tail, in coming from its extreme sweep to the axis or mesial plane of the boat or fish, that either is urged onwards. "Let us suppose," says Dr. Roget, "that the tail is slightly inclined to the right, as shown in the preceding figure. If in this situation the muscles of the left side, tending to bring the tail in a right line with the body, are suddenly thrown into action, the resistance of the water, by reacting against the broad surface of the tail in the direction P R perpendicular to the surface, will cause the muscular action to give the whole body an impulse in that direction, and the centre of gravity, C, will move onwards in the direction C B, parallel to P R. This impulse is not destroyed by the further flexion of the tail towards the left side, because the principal force, executed by the muscles, has already been expended in the motion from R to M, in bringing it to a straight line with the body; and the force which carries it on to L is much weaker, and therefore occasions a more feeble reaction. When the tail has arrived at the position L, indicated by the dotted outline, a similar action of the muscles on the right side will create a resistance, and an impulse in the direction of K L, and a motion of the whole body in the same direction, C A. These impulses being repeated in quick succession, the fish moves forwards in the diagonal, C D, intermediate between the direction of the two forces."

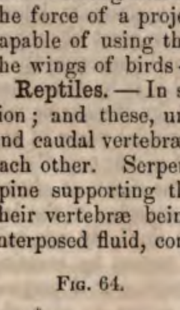
It should be added to this description, however, that fishes in general have the power of "feathering their tails"—that is to say, of so puckering up the lobes in their outward motion, as to make them displace as little water as possible — since the effect of the resistance of the water in this direction must obviously be that of retarding their course; while, on the other hand, they expand these lobes on their return to the mesial line, in order that they may displace as much water as possible; since it is upon the reaction of the water in this direction that they rely for their advancement.

The bodies of fishes are of very nearly the same specific gravity as the water in which they live, owing to the great quantity of fat which most of them contain; so that very little effort is required to keep them at any given height, and their descent or ascent in the water is comparatively easy; the latter being further promoted by the faculty they possess of filling their air-bladder at pleasure with air. When they attach themselves to rocks, it is by means of

suckers, as in other tribes; and when they leap from the surface of the water, it is by a sudden and forcible extension of their bodies after a strong flexion,—the elasticity of the water thus giving them the force of a projectile. Some fishes also, as the flying kinds, are capable of using their long fins in the air almost in the manner of the wings of birds — a hundred yards being no unusual flight.

Reptiles. — In serpents we find the spine as an organ of locomotion; and these, unlike all other vertebrata, have only abdominal and caudal vertebræ, the motions of which are exceedingly free upon each other. Serpents differ from fishes, in the circumstance of their spine supporting their true ribs, as well as in that of the bodies of their vertebræ being attached to each other, not by means of an interposed fluid, contained in a shut cavity formed by the juxtaposition of the bones, but by means of a rounded head on the posterior part of the body of each, which is received into a corresponding socket on the anterior part of the one behind it. The spinous processes, also, of the vertebræ of serpents being in general considerably shorter than those of most fishes, the motions of their spinal column are not only lateral, but in a great measure upwards and downwards also; although some painters and statuaries appear to have a little overdone this matter, and to have represented flexures of the bodies of serpents where no countenance can be given to them by anatomy. There are limits, in this respect, beyond which we cannot allow even the sublime hand of the sculptor of the Laocoon to pass without reproach. But although the motions of serpents are thus very similar to those of "the wandering eel" in its peregrinations on the grass, the former has an assistance which the latter has not, and one which appears to constitute a link in the transition of the spine, as an organ of locomotion, very similar to that constituted by the bristles of the aphrodita, or sea-mouse, in the same transition in the invertebrate. This assistance is the ribs, which in serpents are, in fact, organs, not so much of respiration — as is the case in most lizards, in birds, and in mammiferous animals — as of progres-

Fig. 64.



VERTEBRA OF SERPENT.

Fig. 65.

RIBS OF SERPENT.

sion; and the raising or drawing forward of these ribs corresponds more to advancing a leg than to any other motion of animals furnished with proper limbs. Not only, then, is the spinal column of serpents a means of helping them forwards, but the ribs being at the same time drawn towards their head, the transverse plates on the lower surface of the body, with which they are connected, move forward, as it were, like so many feet, when the spine and the rest of the body are drawn forwards upon them. It is thus that the serpent fulfils the curse pronounced upon the first tempter, "Upon thy belly shalt thou go, all the days of thy life." It is the only "beast of the field"—in other words, the only terrestrial vertebrated animal—which does not employ legs as an organ of progression; but the transition, in this respect, from the serpent to those vertebrated animals in which these organs are both structurally and functionally most developed, is extremely insidious, and furnish another striking illustration of the axiom, that nature never advances by sudden leaps in her productions, and that she knows no chasms in the chain of creation. She has given even to the serpent a kind of rudimentary legs, or, at least, arms, manifesting themselves in a kind of claws, situated in most species under the common covering of the body, but in some few projecting a little beyond it; and in some kinds of lizards — the snake lizard, for example — the improvement in this respect is hardly appreciable. The legs of this animal are scarcely less rudimentary than those of the serpents; and, like the caterpillar among the invertebrate tribes, it probably advances, at least equally, by means of its spine, as by means of its legs. A further step is gained in the case of the land salamander, which, like the centipede, uses its legs—which are considerably more developed than in the snake-lizard—more than its spine as an organ of locomotion; but its legs are still almost as often tilted up into the air as resting on the ground, in the process of walking, and it is not until we come to some of the higher tribes of lizards — as to those of insects in general—that we find the legs exclusively and unequivocally employed as instruments of progression.

Some lizards, also, move up perpendicular surfaces by a species of suction; the soles of their feet, as in the gecko, being provided with a series of soft plates, which, being drawn up at pleasure, produce the requisite vacuum. Other reptiles—as the tortoise — make progress on land by crawling, and the frog by crawling and leaping; others—as the flying-lizard—use their ribs, not, like serpents, as legs, but as wings. In the water most reptiles use their

FIG. 66.

SUCKER OF LACERTA GECKO.

legs as fishes do their fins; and some of them, as turtles, keep themselves afloat by a collection of air beneath their dorsal shield.

Birds.—When on land, the progression of birds is effected by either walking or hopping on their posterior extremities only, birds being the only proper bipeds among the lower animals; and they are enabled to keep themselves erect without effort, since their centre of gravity corresponds to the region where their anterior extremities are attached, owing, in most birds, to the legs being directed forwards, and the toes more elongated; but in some — as the penguin and the puffin — to the trunk of the body being placed almost vertically. Birds are enabled to float in the water, owing to their specific gravity being in general less than that of this fluid, and hence they displace only as much of it as is equal to their own weight, according to the well-known hydrostatic law; and they move along its surface by the action of webbed feet, the swan appearing to use its wings, in addition, almost in the manner of sails. But the characteristic organ of locomotion in birds is their wings, corresponding, in their more essential parts, as well with the pectoral fins of fishes as with the forelegs of reptiles and quadrupeds, and the arms of man. The motions of these are effected by a mass of muscles, weighing more than all the rest of the muscular system of the animal, and arising from a breast-bone of a larger size than is met with in any other class of animals; the immense power thus acquired being no more than is necessary to enable them at once to support themselves in the air, and to move through it with astonishing velocity. The former they effect by continually renewing the column of air below them — and which must be displaced, in order to allow of their falling to the ground — more rapidly than this displacement can take place; and the latter, by using their wings in the manner of oars, while the tail, at the same time, serves them as a rudder. In this way birds are known to have travelled at the rate of sixty, or even one hundred, miles an hour.

Fig. 67.

PENGUIN.

Mammals.—To the motion of fishes in the water an air-bladder is essential; but in the cetaceous tribes this organ, as one of locomotion, is superseded; since, when they desire to rise in the water, all they have to do is to strike a few smart blows with the tail downwards, when their heads are naturally carried in an opposite direction, and when they wish to sink, a few similar strokes with the tail

in the upward direction at once serve to bury their heads beneath the water. A reference to figure 63, when viewed sideways, will at once give the explanation of this simple fact.

The tail, being the chief organ of locomotion among cetaceous animals, is a most powerful instrument; and accordingly, a ship's boat, when struck by the tail of the whale, may be divided, as by an axe, or buried beneath the waters.

Fig. 68.

TAIL OF THE WHALE.

The downward and upward motion of the tail of the cetaceous animals in swimming (attended, as it must be, with a corresponding rising and sinking of the head as it advances) gives to many of them, as they sport near the surface of the water, the appearance of revolving like a wheel, and has led to very false impressions respecting the form of their bodies. The dolphin, accordingly, is always represented in ancient statues and bas-reliefs as a being with a rounded head and arched back; and there are few who see the animal for the first time that can reconcile the slim and tapering creature before them with the blunt-headed, round-shouldered figure with which their fancy has associated it. Generally speaking, the muscles which move the tail downwards in the cetaceous tribes, are stronger than those which raise it; and this is so much the case with the white dolphin, that, according to Pallas, it is accustomed to bend its tail under its body in swimming, almost like that of a boiled lobster; but it is obvious that if the tail be held for an instant stationary in this position, while the body is advancing, the effect will be to depress the head, for the same reason that the continued inclination of the tail of fishes to the right side serves to turn the animal in this direction. During the whole sweep, however, that the tail is making downwards, the head must incline upwards; and this appears to be another means, in addition to their little specific gravity, by which these animals are enabled, with very little effort, to keep the top of their heads above the water. Their total immersion in this fluid is always prejudicial to them; and nature has therefore rendered it a forced state, not only by opposing difficulties to their descent, but by making their muscular motion to co-operate with their lightness in bringing them again to the surface.

Very few quadrupeds are capable of moving through the air—the bat, the flying squirrel, and some species of lemur being among these,—and this they effect, not like the flying fishes and birds,

Fig. 69.

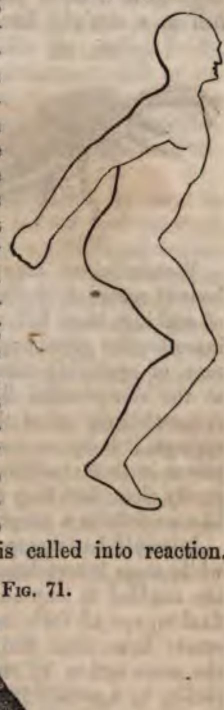
HARPYIA PALLASII.

alone by their anterior extremities, nor, like the flying lizards, by their ribs, but by wing-like membranes extended between their anterior and posterior extremities, the motions of both of which are requisite to call them into action. Quadrupeds in general use their upper limbs only in conjunction with their lower in the act of progression; but some few, as squirrels and apes, use them also as we do our arms, the arrangement of their skeleton being expressly adapted for the purpose. In standing, they use in general all the four legs; and as the centre of gravity is thus preserved without effort, they easily sleep in this posture. Some few, however, as the kangaroo and jerboa, rest on their hinder legs alone, the centre of gravity falling in them almost perpendicularly; but such also use their strong tails, like another leg, to steady them. In climbing, some, like the walrus or the lizard, seem to attach themselves to any surface, by forming a vacuum with the soles of their feet; but the majority use their claws for this purpose, and these in some tribes, as the sloths and ant-eaters, are so long, that they are almost incapable of walking on a horizontal plane. Their manner of performing the trot, gallop, and amble, we shall not stop to describe, but conclude this section of our work with a few remarks on

Leaping.—The leaping of terrestrial animals, from man down to the flea, consists of a sudden and forcible extension of the limbs, after flexion, from a medium which offers more or less resistance. The length of the body is thus suddenly increased; and as it presses on any unyielding medium, it is reacted upon with a force equal to

that with which it presses, and an impulse is accordingly thrown into it, sufficient to detach it, and project it to a greater or less distance. But while the process is of course very much facilitated by the fulcrum being firm and elastic—a fact well known to opera-dancers and vaulters by profession, who commonly use spring-boards to assist them in their bounds—it cannot be effected by terrestrial animals from the water, nor even from soft, boggy ground, unless their bodies be very light, or their feet very broad, because the points by which they in general press upon their fulcrum, compared with the weight of their whole body, namely, the extremity of their legs, are so small as to be resisted only by the very narrow columns of this fulcrum, which therefore, instead of re-acting upon them, immediately give way to the pressure which they sustain. Such, however, is not the case with fishes, the broad flat part of the tail of which, or if the tail be tapering, at least the broad flat part of the body which leads to the tail, is brought directly to bear upon the water; so that a very considerable column of resistance, in proportion to the whole bulk and weight of the animal, is called into reaction.

Fig. 70.



Nor is it peculiar to fishes to employ their tail in the process of leaping; some quadrupeds, as the kangaroos, using their tails, in conjuction with their very long hind legs, to assist their bounds. Thus they not only employ an additional limb, the sudden extension of which, after flexion, adds to their impulse; but, pressing with an additional joint upon the fulcrum, they thus diminish any tendency which it may have to yield to the pressure which they impose upon it. Both in the kangaroo and the jerboa, or jumping rat, and also in the hare, rabbit, squirrel, and others, the muscles of the hind legs are also greatly developed, in order to give the force necessary to effect their extended leaps; while the

Fig. 71.

THE KANGAROO.

fore feet, which are little employed in locomotion, are comparatively much smaller and shorter. In ascending a hill this arrangement is very beneficial, though it greatly impedes these animals in descending one at a rapid pace; thus they seldom attempt to run down a hill in a straight line—their course is generally diagonal. Some insects, also, use their tail in leaping. This is the case with the velvet spring-tail, which leaps, by jerking its tail downwards from under its body, in the same manner as the grasshopper, the froghopper, or the flea, by jerking down its legs; that is to say, by suddenly extending them, after they have been brought to a state of full flexion.

FIG. 72.

PODURA.

Wonderful as may be the leaping of fishes, and much as the bounds recorded of these animals exceed those which man is capable of making, they fall very short of what we witness every day in insects—the grasshoppers and fleas, for example, being capable, with ease, of springing some hundred times their own length. Looking at the comparative lightness of these animals, however, and the favourable nature of the fulcrum on which they rest in making their springs, it is by no means certain that they employ more muscular power in their vaultings than fishes; while, on the other hand, it is pretty clear that they do not in general exercise them with anything like so definite a purpose, or so much precision.

It would be improper to leave this subject without remarking, that while some invertebrate aquatic animals—for example, the cuttle—are enabled to leap out of the water by the sudden extension, after flexion, not of their tails, but of their numerous arms or other processes from their bodies; others—for example, the oyster—effect the same action by sudddenly bringing together the valves of their shells, by a strong muscle situated near the hinge, by which means a portion of the previously-contained water is rapidly expelled, and made to bear downwards upon that in the immediate vicinity of the animal, which, reacting of course upon the sudden pressure, communicates an impulse which forces it above the surface. The feats of the oyster, however, in this way are very insignificant, and it is not easy to say for what purpose they are performed.

In conclusion, we would briefly remark, that so nicely and admirably are the organs of locomotion in quadrupeds adapted to each other, that an anatomist, from the inspection of any one bone of the very many which compose the skeleton—in man no less than two hundred and forty-six—is enabled to infer the general form and relations of all the rest, as well as of the ligaments which connect, and the muscles which move them. Nay, more:—so intimately

does the structure of this shell, as it were, of the body correspond with that of the internal parts, that from this one bone he may almost give a description of every organ of the animal—of its propensities and habits. Can this correspondence be the work of a blind chance? or does it imply a unity of design, an extent of benevolence, and a vastness of power, indicative of a ruling Providence—the Architect alike of the star of the firmament, and of the mite which plays in the sunbeam—whose hand is traced equally in the immensities of magnitude and of minuteness—the Almighty Father of the Universe, and of everything that astounds and delights us in its construction?

Senses of Animals.—The next function of which we have to speak is Sensation; and it will be convenient, in the first place, to devote a few pages to a short description of the senses in particular, and of the several organs by which, in different animals, the functions of smell, sight, hearing, taste, and touch, are respectively performed. We shall then pass to a general view of Sensation, Emotion, Instinct, and Thought; and conclude our subject with an account of Voice and Speech in Man, particularly as distinguished from the cries, song, and buzzing of inferior animals.

Smell.—In quite the lowest orders of animals the organ, if any, specifically appropriated to smell is in general very obscure, although some of them in which this is the case—the cuttle, for example—display this function very remarkably. It is, perhaps, in most of them, merely a modification of touch, and performed equally by every part of the surface of the body. In the snail the seat of smell has been commonly considered to be the short feelers; but apparently without any good reason.

FIG. 73.

CRAY-FISH.

Insects in general smell very acutely; and in them the seat of this function has been at different times supposed to be their stigmata, or air-holes, their palpi, or commonly-reputed organs of taste, and their antennæ, or organs of touch in general. In the crustaceans, as the cray-fish and lobsters, which are among the few of this order that have a sufficiently obvious olfactory nerve, it is manifestly their smaller antennæ, at the root of which the nasal cavities are situated. In these animals, however, as well as in all aquatic animals, smell is rather a modification of taste than a distinct function, the vehicle of the impression being not air, but water. Such is also the case in fishes; in them the nasal cavities are situated, in general, on the sides of the snout, and are lined by a plaited membrane, sometimes not unlike the teeth of a comb, for the distribution of the proper nerve. The distance at which some fishes scent their prey is immense; and they are so acutely sensible of odorous bodies, that the very perfection of the function is often fatal to them. Some kinds of fish are so strongly allured by aromas, that by smearing the hand over with them, and immersing it in water, they will often flock towards the fingers, and may be easily taken. In all fishes, external openings, or nostrils, are very apparent. They generally constitute, it is true, only blind sacs; but their inner surface is of considerable extent, and upon their lining membrane, a pair of large nerves, analogous to the olfactory nerves of man, are distributed.

In reptiles, the nasal cavities have both an internal and external opening; the former being, in frogs, turtles, and serpents, in the palate; but in lizards, in some of which, as the crocodile, they are exceedingly long, in the pharynx, or muscular bag, at the back part of the mouth. Most reptiles, also, have a kind of a movable lid at the aperture of their nasal cavities, by which they close them when under water; this medium being apparently but ill-adapted in them to the function of smell. The proper vehicle of the impression in reptiles, as well as in birds and mammiferous animals, is air; and this the former draw through their nasal cavities during inspiration, effecting the operation by depressing their lingual bone, and thus enlarging the cavity of the mouth.

In birds, the nasal cavities are in general very large, their external aperture being in the upper mandible, and their internal in the pharynx. The olfactory nerve is very large in carnivorous birds, and its great size, together with the great length of the nasal cavities, serve to explain the immense distance at which some of them — the vulture, for example — are known to scent carrion: it is said to be capable of doing this over the whole breadth of the Mediterranean!

The nasal cavities of mammiferous animals run in general horizontally; but in the cetaceous tribes their direction is perpendicular,

the outer opening being at the top of their heads. Many animals of this kind—as the porpoise, the whale, and the narwal—are generally regarded as destitute of smell, since they have no proper olfactory nerve; and certainly the hard and dry lining of their nostrils, like that of the proboscis of the elephant, is apparently very little adapted to this sensation. The projecting bones, by which the nasal cavities are, in most animals, more or less divided, are, in quadrupeds, extremely complicated, being, in most herbivorous species, both variously convoluted, and pierced sometimes like lattice-work, and, in most carnivorous, lamellated like the leaves of a book—a structure calculated, by increasing the surface, together with the great length in general of their snout, and the large size of their olfactory nerves, immensely to increase the acuteness of their smell. The "intellectual noses," as they are called by Lord Byron, of dogs are proverbial; and the distance from which many other quadrupeds, particularly such as are carnivorous, are sometimes attracted by the smell, is wonderful; white bears, for example, being found to come swimming to the Greenland ships, when a whale is cutting up, from all quarters, and far out of sight. Some quadrupeds, as the hog, the peccari, and the tapir—have a remarkable power of moving the extremity of their snout; but this is probably less for the purpose of smell than for that of burrowing, &c., their snout being to them, as its proboscis is to the elephant, a kind of hand.

In man, the sense of smelling is performed by means of a soft pulpy membrane, called the Schneiderian membrane, full of pores and small vessels, and lining the whole internal cavity of the nostrils; it is thickest upon the septum, or partition between the nostrils, but thinner in the sinuses, or cavities, hollowed out in the bones about the nose. The nerves of the nose being almost naked, require a defence from the atmospheric air, which is continually drawn through the nostrils, and blown out again by respiration. Nature has, therefore, supplied this part with a thick, insipid mucus, very fluid in its first separation, but, by the air, condensed into a thick, dry, and more consistent crust. By this mucus the nerves are defended from drying and from pain. It is poured out from many small vessels, and deposited partly in numerous cylindrical pits, and partly in the round visible cryptæ or cells scattered all over the nostrils. The mucus is accumulated in the night-time; but in the day it either flows spontaneously, or may be more powerfully expelled by blowing the nose. By becoming dry and harsh, it irritates the very sensible nerves of the lining membrane, and is then removed by sneezing. The tears descend into the nose by a channel proper to the muscles, and moisten and dilute the mucus.

Sight.—With respect to sight, it is equally doubtful, as with respect to smell, whether there be any specific organ for this func-

tion in quite the lowest tribes of animals; although some of them, as the armed polype, the sea-feather, and some corallines certainly do see, or at least are capable of distinguishing light from darkness, the former being always found to move towards the light, and the two latter from it. It is, however, probably by a kind of touch that they do this, rather than by sight, properly so called; and of this the numerous papillæ on the surface of the body may be presumed to be the chief instruments; so, also, the first appearance of distinct organs of vision is that of stemmata, as they are called, or small knobs, more or fewer, projecting from the surface of the body, as is the case in the leech; and what are regarded as the eyes of the snail, are little more than similar knobs, placed at the extremity of their long feelers, and capable of being retracted by the muscles of the latter, into which they descend, as into the inverted fingers of a glove. Organs of this kind may serve, indeed, to distinguish

Fig. 74.

POULP, OR OCTOPUS.

between light and darkness; but it is impossible that they can convey any impression of distinct images of objects, since they have not the conditions necessary to produce such refractions of the rays of light as are essential to this end. Among the few animals of this description which are provided with proper eyes, is the cuttle-fish tribe, in which those organs are very large and prominent. They consist essentially of a dense opaque globular membrane—the sclerotic coat—filled with a transparent fluid, enveloping a small lens, and smeared on its concave side with a black pigment, the use of which is to absorb the superfluous rays of light, and immediately

under which lies the retina or expansion of the optic nerve. This membrane is perforated anteriorly by a kidney-shaped pupil, through which the rays of light are transmitted to the retina; and over the whole is extended a second membrane, so folded on itself, as to constitute a kind of eyelid.

Similar to the stemmata of some worms are what are called the simple eyes of insects; and such are alone found in the spider and scorpion: they seem to be organs rather of touch than of sight, although they have been presumed by Blumenbach to serve to distinguish near objects. Very different from these are the so-called compound eyes of insects, such as are met with, without any simple eyes, in the beetle and butterfly; while others, as the bee, have both. They are for the most part extremely large; varying, however, between about one-sixtieth and one-fourth part of the weight of the whole body. Their structure is eminently beautiful; consisting, as they do, not of coats and humours, but principally of a series of pyramids of nervous substance connected together, the apices being on the bulbous extremity of the optic nerve, and the bases, invested each by a thick transparent membrane of a hexagonal shape, at the circumference of the eye. This membrane, presenting thus numerous facets, which look in every direction, is called the cornea, and seems to be in insects the only instrument of refraction, the images of objects being most probably impressed, by this means, directly on the base of each pyramid, which is thus a kind of distinct eye. They have no lens and no pupil, or rather the whole surface of the cornea is one large pupil, there being no opaque coats to render a proper pupil necessary; and they are destitute both of eyelids and of muscles to move the eye, the numerous directions of the facets of the cornea rendering the latter superfluous. How strikingly different is this description of eye which characterizes insects which fly, and require therefore an ample field of vision, from the simple eye found in the grovelling kinds, which either do not see, strictly speaking, at all, or certainly only quite contiguous objects! Further, in insects which fly by night, like the moth, there is, in place of the black pigment lately mentioned as found in the cuttle, a substance of a resplendent green or silvery

Fig. 75.

HEAD AND EYES OF THE BEE.

aa, antennæ; A, facets enlarged; B, the same, with hairs growing between them.

colour, serving not to absorb, but to reflect the rays of light; and thus enabling them to see by a much more obscure light than would otherwise have been necessary.

Among vertebrate animals, fishes have an eye somewhat similar to that of the cuttle; consisting essentially of a spheroidal sclerotic coat, containing the chief humour of the eye, a lens, which, as in the cuttle, is almost globular, and a retina, which is often plaited, as it were, into numerous folds, arranged like the meridian lines on a globe. They have, however, in addition, a proper cornea like insects, presenting, not indeed numerous facets, but one uniformly convex surface, although the convexity is very slight; and they have further, what insects have not, a perfectly formed iris, or circular curtain, placed before the lens, in which, and not, as in the cuttle, in the sclerotic coat, the pupil is situated. The rays of light accordingly traverse, in these animals, first the transparent cornea, and afterwards, in order, the anterior portion of the humours of the eye, the pupil, the lens, and the posterior portion of these humours; by all which, except the pupil, they are more or less refracted, till they are at length brought to a focus on the retina. The chief peculiarity in the eyes of fishes, as contrasted with those of the superior tribes of animals, is the comparative flatness of their cornea, and convexity of their lens; it appearing to have been the object of nature to effect the necessary refraction of the rays in them principally by the latter; the iris, moreover, in fishes, is almost entirely motionless, so that the size of their pupil is always nearly the same. In general they are destitute also of proper eyelids; the eyeball moving behind the common integuments—to which it is attached by very relaxed cellular tissue—as behind a piece of thin glass or horn. In some few fishes, however, as the sun-fish, Cuvier has found a regular circular eyelid, the opening in which is contracted by a sphincter, and expanded by five radiating muscles. The direction of the eyeballs is usually outwards; but in some few fishes, as the star-gazer, it is upwards; and in the plaice, flounder, dab, halibut, turbot, &c., the eyes are placed both on one side of the body—an isolated instance, according to Blumenbach, of a want of uniformity in such organs. The object, however, of such an arrangement in this instance is obvious; for as these animals, destitute as they are of an air-bladder, are destined to continue always with one side in the mud at the bottom of the water, an eye on this side would have been superfluous to them. The most singular situation of the eyeball, however, is that of the Surinam sprat, the orbit extending in this fish so far above the head, that the eye, as the animal swims near the surface, is partly in and partly out of the water; and all its parts correspond with this strange structure, the pupil being partially divided into an upper and a lower portion, and the lens

consisting of two globes, an upper and a lower one, attached together. It appears that the superior part of the eye is, like that of terrestrial animals, adapted to refract rays transmitted by air, and the inferior part, like that of aquatic animals, those transmitted by water; and that the refracting power of the several parts of the eye is accordingly much less above than below. It remains only to remark, that in some fishes, as the skate and shark, there is, as in insects that fly by night, a resplendent substance at the bottom of the eyeball, instead of the black pigment which is usually found there; its use being rather to increase than diminish the number of rays which fall upon it.

The eyes of reptiles in general do not differ materially from those of fishes, except that they appear to possess the power, of which those of fishes are destitute, of adapting themselves to refract rays as transmitted either by air or by water. We have already hinted, when speaking of the singular eye of the Surinam sprat, that the refracting power required is different in these two cases, as any one may satisfy himself by attempting to distinguish minute objects placed in water, with his head likewise immersed in this fluid. The reason that he cannot do this is, because, though there is a sufficient difference between the density of the humours of his eye and that of the air, to bring the rays transmitted by the latter to a focus on the retina, there is not a sufficent difference between the density of these humours and that of water, to do the same by rays transmitted through this fluid, so that such rays are not brought to a focus sufficiently soon. Hence, divers in some places are in the habit, when they descend into the water, of using extremely convex glasses, in shape almost like the lens of fishes, and turning their eyes, by this means, as it were, into those of an aquatic animal. But how do reptiles manage this? Not by using spectacles, nor by increasing the density of their humours; but by increasing the distance between the cornea and retina—which they effect by compressing the globe of the eye by proper muscles given to them for that purpose—so that the rays which, from the defective refracting powers of their humours, would have otherwise formed a focus *beyond* the retina, now form a focus *upon* it. When again in the air they relax these muscles, and the retina again approaching the cornea, still receives the focus of the rays, which, as passing now through air, are sufficiently refracted for the purpose. Whether we regard, then, the heart and blood-vessels, the respiratory organs, or those of the senses, in these tribes, we trace equally distinctly the main object which nature had in view in their construction. The motions of the iris in reptiles—now for the first time perceptible—are still extremely languid, and the form of the pupil is very various, being rhomb-shaped in the frog, vertically oval in the crocodile, &c.; but this

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probably makes no difference in the phenomena of vision. With respect to eyelids, all reptiles are furnished more or less perfectly with these, except serpents, which, in being destitute of proper eyelids, resemble most fishes. The direction of the eyeball is, as in most fishes, commonly outwards; but in the crocodile it is, as in the star-gazer, a little upwards as well as outwards, obviously for the purpose of enabling the animal to see its land prey, as it floats leisurely just beneath the surface of the water. Reptiles have also, all of them, again excepting serpents, another organ which all fishes want,—namely, a lachrymal gland, the secretion from which serves to bedew the anterior part of the eye with moisture, and thus to facilitate the motions of the eyelids. Such an organ would evidently have been quite superfluous in fishes, which are always under water; but it is particularly necessary in amphibious animals, which, when on land, must furnish from their own resources a fluid so abundantly supplied to them when in the water from without. This gland is accordingly of immense size in turtles; and the allusion to crocodile's tears, as flowing easily and copiously, is familiar to everybody.

The eyes of birds are remarkable principally, like the compound eyes of insects, for their great size, the use of this being in both the the same—that of enabling them, when on the wing, to see objects at a great distance. With respect to the cornea and lens, they are directly opposed to those of fishes; since, while the cornea is comparatively flat, and the lens almost globular in fishes, in birds the cornea is remarkably prominent, and the lens has very little convexity. The motions of the iris in most birds are extremely rapid, and in some apparently voluntary.

Fig. 76.

LATERAL AND FULL VIEW OF EYEBALL OF OWL.

a, very convex cornea; *b*. sclerotic coat, surrounded at *c*, by bony plates.

The pupil is in some, as the dove and goose, transversely oval, while it is vertically oval in others: generally speaking, indeed, it has the former shape in herbivorous animals, whether birds or quadrupeds, and the latter in carnivorous. All birds have proper eyelids, the lower of which alone is movable; and they have, in addition, another membrane called membrana nictitans, which is merely a movable fold of the external membrane of the eyeball: it is not quite proper to birds—being found also in some fishes and reptiles—but it is most remarkable in them. With very few exceptions—the owl among others—the direction of the eyeballs is, in birds, outwards. Such birds also, as well as insects and fishes, as go in search of their prey by night, like the owl, have a shining substance at the bottom of the eyeball, for the purpose already alluded to. In some birds with piercing sight, as the falcon and crane, the flattened optic

nerve has one of its surfaces folded into numerous plaits, bearing the same relation to the other as the leaves bear to the back of a book; and the extent of surface thus gained may be easily imagined.

Among the mammiferous animals, the cetaceous tribes, as we should expect from their habits, have eyes very similar to those of fishes; the cornea being comparatively very flat; and the lens almost globular, while they are destitute of proper eyelids—a kind of membrana nictitans alone supplying their place — and of a lachrymal gland. In the other tribes, the comparative convexity of the cornea and lens is intermediate between that of these organs respectively in fishes and birds; while the motions of the iris are the mean, as it were, of those of reptiles and birds: in some quadrupeds, moreover, as the cat, they seem to be in some degree voluntary. The form of the pupil is transversely oval in the pecora and solidungula, and vertically oval in the Feræ. The direction of the eyeballs is in most mammiferous animals outwards; in the ape, however, babboon, monkey, and some few others, it is, as in man, directly forwards: further, in some quadrupeds, as the camelopard, the eyeball, though naturally directed outwards, may be turned so far backwards as to enable the animal to see distinctly behind it. Like the nocturnal animals, also, of other tribes, quadrupeds which prowl by night, such as the lion, lynx, cat, bat, &c., have the structure as already more than once described, calculated to enable them to distinguish objects in comparative darkness. On the other hand, where the habits of the animal are such as to exclude it altogether from the light, as no structure of the eye could have compensated for the want of this essential condition of sight, nature has denied them a visual apparatus altogether — as in the case of the mole, which has no optic nerve, and an eye so small, that its existence has been doubted; but whatever be its size, in all animals the eye is a perfect optical instrument, and admirably adapted to the circumstances in which each species is placed. We know it to be composed, as we shall hereafter see, of membranes and humours of different densities, so that they may transmit and refract the rays of light with the greatest regularity and exactness. In the eyes of all animated beings, we see the wisdom and beneficence of the Creator. If the animal dwell in water, the cornea is flat, and the lens spherical; if on the surface of the earth, we find, on the contrary, the cornea more projecting, and the lens more flat; and again, if it wing its airy flight above us, its cornea is the most projecting, and its lens the flattest of all.

Hearing. — In the very lowest tribes of animals it appears that this function, like those of smell and sight, is merely a more delicate kind of touch, and performed equally by the whole surface of the body. The greater number of animals of this description have

no obvious auditory apparatus, the cuttle being among the few exceptions, and furnishing perhaps the best example of an ear in its rudimental state. In this animal it consists merely of a membranous bag filled with liquid, situated in a tubercle of the cartilaginous ring which surrounds the gullet, and surrounded on all sides by cartilage. Upon the outer surface of this bag is distributed the auditory nerve; while, within the liquid which it contains, are some little pieces of earthy matter, presumed to be necessary to render the vibrations of the liquid, on which sound depends, sufficiently forcible to make the requisite impression on the nerve.

In the greater number of insects, also, the auditory apparatus is very obscure; although it is certain that they do hear, and even very acutely. The immediate seat of the function has been presumed to be the membrane which connects their antennæ with the head — but spiders hear which have no antennæ, and grasshoppers after these have been removed. In all likelihood, it is, in the majority of insects, merely a variety of touch, and common, therefore, to the greater part of the surface. In such animals as present any appearance of a distinct auditory apparatus, as the cray-fish, it is very similar in its structure to that of the cuttle; consisting, in like manner, of a bag filled with liquid—situated, in this instance, in a bony cylinder at the root of the larger antennæ — an auditory nerve expanded upon it, and some pieces of earthy matter in the liquid which it contains. In the cray-fish, however, unlike the cuttle, the bag in question is not surrounded on all sides by the hard mass which contains it, but is near the surface of the body, in contact with a thin membrane—the first approach to the external parts of the auditory apparatus, as met with in the higher tribes of animals.

Nor is the auditory apparatus of most fishes much less simple than that of the invertebrate animals. The membranous bag, however, above spoken of, is connected in general with three semicircular canals, of a similar structure, and furnishing more space for the distribution of the auditory nerve; and the earthy pieces, within the liquid contained in this bag, have begun to assume the appearance of regular bones. Still, in most fishes all these parts are buried within the skull, and send no process to the surface; in some of the cartilaginous tribes alone this bag being prolonged to the upper and back part of the head, where the blind termination of it is covered by the common integuments of the body. One fish alone — the lepidoleprus trachyrynchus—presents any appearance of a canal, proceeding from the surface to meet the internal parts, as in all animals above the rank of reptiles. But the extreme simplicity of the auditory apparatus in fishes and other aquatic animals, is precisely what we should have looked for in beings destined to hear through the medium of water; the vibrations of which, being so much more

powerful than those of air, would render the complicated apparatus, requisite in terrestrial animals, in them superfluous.

Accordingly, it is in reptiles that we meet with, for the first time, more or less constantly, not indeed a canal leading from the side of the head towards the ear—which none of them have—but one leading from the back of the pharynx, to form a cavity, interior to which all the parts already described are situated. This cavity is called the tympanum, and contains more or fewer distinct bones, moved by proper muscles, and serving to increase the impulse derived from the vibrations of the air, and to convey it to the internal parts, which now take the name of labyrinth. Some additions, also, are now made to this; for, besides the three semicircular canals, already described as branching from the common bag in one direction, there is now a second series of canals, of a very complicated structure, called cochlea, branching in one another, and affording, of course, still further space for the expansion of the auditory nerve. It is true these parts are not common to all reptiles; serpents, for instance, having no tympanum—although they have a small bone, analogous to those which, in other reptiles, are situated in this cavity, but which, in serpents, is lost in the muscles of the jaws—and none but some of the highest orders of lizards, as the crocodile, having a cochlea. The last-named animal, moreover, makes the first approach to the well-known appendage to the ear, technically called the pinna; being furnished with a kind of external flap, with which it closes the auditory apparatus at pleasure. It is in this way, probably, that the animal excludes too intense sounds when under water; but it appears that the greater number of amphibious animals are capable of adapting their auditory apparatus, at least partially, to the medium in which they are, by putting all the parts upon the stretch, by means of the muscles already spoken of, when in the air, so as to qualify them to receive slighter impressions, and by throwing them all into a state of relaxation when under water, so as to prevent them from being stunned by more powerful ones.

In birds, at length, we constantly meet with a short canal, leading from the side of the head, and meeting that coming from the pharynx, in the tympanum. They have but one bone in this cavity; and the general structure of the parts of their labyrinth is very similar to that of the higher orders of reptiles. Birds in general want a proper pinna, or ear-flap, its place being commonly supplied by a small tuft of feathers: the owl, however, has something very similar to this part as found in mammiferous animals.

The auditory apparatus of the mammalia is in general little more than a greater development of the same parts as are found in birds. The bones within their tympanum are from two to six in number; and all have a pinna except the cetaceous tribes—in which it would

Fig. 77.

EARS OF BIRDS.

a, Peregrine Falcon; *b*, Day owl; *c*, Tawny owl; *d*, Long-eared owl; *e*, Barn owl.

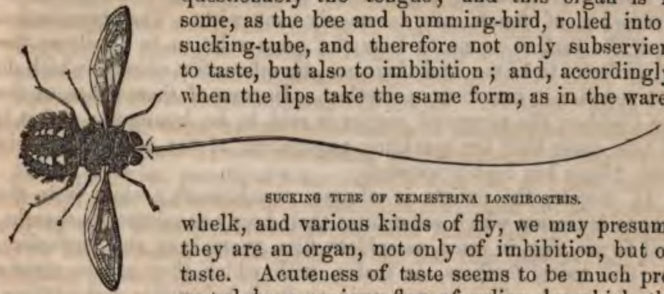
have been superfluous, from the vibrations of water being too strong to require to be collected by this means — and some others, which either dwell much in the water, as the shrew, or burrow under ground, as the mole, in which, for an obvious reason, it is still less called for. The shrew, however, is provided with a kind of flap, like that of the crocodile, the principal use of which seems to be, so far from increasing the intensity of the impression, to diminish it when the animal is under water. The great size of the pinna in some quadrupeds, and the frequency and rapidity with which they move it in any direction, are familiar to everybody; and may well account, in conjunction with the complicated and delicate structure of the internal parts of the ear, for the extremely acute hearing which they enjoy, and which is so necessary, in many instances, to their security. Hence, a frequent and rapid motion of the ears is, in all animals, with justice regarded as indicative of a timid disposition. We do not here allude to the organs of sight and of hearing in man, since their description will more appropriately fall under our treatises on Optics and on Acoustics.

Taste is certainly, not only in the lower, but in all tribes of animals, merely a more delicate kind of touch; and is situated, for the most part, not exclusively in the tongue, palate, or any other individual organ, but in the whole interior of the mouth.

Although, therefore, in many animals, as the snail, cuttle, and fishes in general, as well as in some individuals of the superior classes, the tongue is hard and cartilaginous, and apparently very little adapted to this function—nay, although it is, as in the flying-fish and gar-pike, altogether wanting—we have no reason to believe that they are destitute of taste; and the same thing may be said of the numerous animals in which the tongue is covered more or less perfectly, with prickles, or even with feathers, like the toucan, or scales, like one kind of bat, which must, in a great measure, obviate the contact

with it of sapid substances. The immediate instrument of taste seems to be certain pointed projections, called papillæ, with which the whole membrane lining the mouth is more or less abundantly furnished; and that organ will be, of course, in all animals the principal seat of this function, on which these papillæ are most copious. In man this is the tongue, the papillæ of which are larger and softer than those of the skin, perpetually moist, and performing the office of touch more exquisitely than the small and dry cutaneous papillæ.

FIG. 78.



SUCKING TUBE OF NEMESTRINA LONGIROSTRIS.

In the greater number of animals, also, it is unquestionably the tongue; and this organ is in some, as the bee and humming-bird, rolled into a sucking-tube, and therefore not only subservient to taste, but also to imbibition; and, accordingly, when the lips take the same form, as in the wared whelk, and various kinds of fly, we may presume they are an organ, not only of imbibition, but of taste. Acuteness of taste seems to be much promoted by a copious flow of saliva, by which the sapid particles are dissolved; and it may be presumed, therefore, that it is much greater in the herbivorous than in the carnivorous birds and quadrupeds, as indeed the necessity which the former are under, but from which the latter are exempt, of distinguishing wholesome from deleterious herbs, would seem to require. Carnivorous animals, on the other hand, are directed to their food principally by the smell.

Touch — the most general of the sensations, and of which all the rest are perhaps only varieties—is seated, collectively speaking, in the whole surface of the bodies of animals; although it is in each much more delicate in certain parts of this surface than in others, owing to the greater number of papillæ with which they are furnished, and which are generally the immediate instrument as well of touch as of taste. The common integuments of the bodies of animals in general consist principally of the scarf-skin or cuticle; a substance immediately below this, called corpus mucosum, of which the nails and hairs are merely modifications; and the true skin or cutis, the seat of the papillæ in question; and there are few animals, even of the lowest tribes, which have not all these envelopes in one form or another. In the armed polype indeed, the sea-blubber, the slug, the earthworm, and many similar animals, the cuticle takes the form of mere mucilage; while in the corallines, on the other hand, it assumes that of a calcareous mass, by which their bodies are invested. In others,

again, it is the corpus mucosum which gives them their earthy covering, a proper cuticle being found exterior to it, as in the sea-urchin, the star-fish, and all the testaceous tribes: the sharp prickles, also, on the shell of the sea-urchin, as well as the hairs of the earth-worm, and numerous other animals of this tribe, are merely modifications of the same substance. A proper cutis seems, indeed, to be wanting in the corallines, as well as in some other animals of quite the lowest orders; but in the testaceous tribes, as the oyster, the cloak is probably a modification of this part, and it is accordingly upon this, or some corresponding organ, that the tentacula, or immediate instruments of touch, are commonly met with. The perspiration from the surface seems to bear the same relation to touch as the saliva bears to taste; and there are, therefore, few animals which do not perspire in one form or another. In some of these tribes, as the sea-blubber, the perspired matter is said to be luminous; and it is to this cause that the sparkling appearance of the sea by night in some places has been attributed.

In insects, the cuticle is always membranous; while it is the corpus mucosum which constitutes their horny or calcareous sheaths, and forms, also, in some, as spiders, flies, gnats, bees, and butterflies, the fine hairs, feathers, or scales, with which they are in certain parts invested. The proper cutis, again, is below this, constituting, in the lobster, for example, its membranous pellicle. This part is, however, so completely defended, for the most part, from the contact

Fig. 79.

VARIOUSLY FORMED ANTENNÆ OF INSECTS.

of external substances, that to most insects are given in addition antennæ, palpi, cirrhi, &c., called in general feelers, situated commonly about the mouth, and the chief seat, in them, of the function of touch.

The cuticle is membranous also in fishes, and immediately invests their scales, as well as the bristles of the stickleback, the tubercles of the sturgeon, &c., all which are formed by the corpus mucosum. Under this is the cutis.

Not only are the smell and taste of fishes very acute, but their touch not less so than that of animals in general. It is astonishing, however, what an extreme degree of heat some fishes can bear. In the thermal springs of Bahia, in Brazil, many small fishes were seen swimming in a rivulet which raised the thermometer eleven degrees and a half above the temperature of the air. Sonnerat found fishes existing in a hot spring at the Manillas at a hundred and fifty-eight degrees Fahrenheit; and Humboldt and Bonpland, in travelling in South America, perceived fishes thrown up alive, and apparently in health, from the bottom of a volcano, in the course of its explosions, along with water and heated vapour that raised the thermometer to two hundred and ten degrees, being but two degrees below the boiling point.

The bodies of most fishes are covered with small brilliant plates of a horny nature, called scales; but in certain kinds these are wanting, as in the turbot, in place of which are found osseous or cartilaginous protuberances in some species, and in others a very smooth skin, without scales or rugosities, but covered with a thick gelatinous secretion. It was observed by Steno, in the skate, that this slimy matter was poured out from numerous orifices regularly placed near the surface; and Dr. Monro has recorded his discovery of a very elegant structure for the preparation of this mucus between the skin and muscles. The secretion is so viscid that it is with great difficulty pressed out. There is a species of carp — the rex cyprinorum of Linnæus—that seems to hold a middle place between the rough and smooth-skinned fish; the upper part and back is covered with scales, while these are altogether wanting on the lower part and belly.

In reptiles the cuticle is either membranous, or, as in the frog, consists merely of mucilage, as it does in many worms already noticed. The corpus mucosum in these animals assumes the form either of a soft, viscid substance, as in frogs; of a horny shield as in tortoises; or of scales, as in serpents and most lizards; some of the latter, however, as the crocodile and alligator, have it again in the form of hard plates, like the shields of tortoises. It is of the corpus mucosum, also, that the claws of such reptiles as have them are constituted The proper cutis is situated under this; and as the papillæ

re most numerous about the soles of the feet, we must it is in this part principally that the touch of reptiles

[illegible]iration of reptiles is in general very copious; that of the sa[illegible], for example, being so much so, as to extinguish flame, and thus to have given rise to the fable of its being capable of living in the fire. In some, as the toad, the perspired matter is of a poisonous quality; and in one kind of lizard it is so acrid as to blister the fingers.

In birds, the cuticle is again membranous; while the corpus mucosum assumes the form, upon the mandibles, of a bill; upon the body in general, of feathers; upon the legs, of scales; and at the extremity of the toes, of claws. Under this is the cutis, which, abounding in papillæ, most in general below the bill, particularly in the swan, goose, and duck, may be presumed to render this organ the most sensible to external impressions.

Fig. 80.

BILL AND TONGUE OF WILD DUCK (*Anas boschas*).

In mammiferous animals, the membranous cuticle covers a corpus mucosum, generally of a soft viscid consistence, but in some few animals of this class, as the rhinoceros, armadillo, scaly ant-eater, &c., assuming the form of hard plates, like those of the crocodile and alligator. It is of the corpus mucosum, also, that are constituted, in some few, as the duck-billed animal, a perfect bill; and, in the greater number, the hair, fur, wool, bristles, quills, &c., with some one or other of which their bodies are covered; as well as the horns, claws, hoofs, &c., with which many of them are furnished.

The cutis, lying under this, is, in all, the organ of touch; which is most acute, in the duck-billed animal, upon the bill; in the carnivorous tribes, at the root of the whiskers; in those with movable snouts, as the mole, hog and elephant, upon that organ; in the bat, upon the membrane between their fingers, commonly called their wings; and in most of the Glires, as the squirrel, as well as in apes and other animals of this description, at the tips of the fingers; since it is in these organs respectively that the papillæ are most abundant. It is unnecessary to point out how admirably this corresponds with the habits of each of these animals; and the delicacy of touch which some of them enjoy in the organs in question is wonderful — an elephant, for example, being able to distinguish, by the tip of its trunk, between the most minute objects, and a bat being capable, though deprived of the use of its eyes and ears, to direct its rapid flight through the most intricate places, the touch alone of its membranous wings sufficiently apprising it of the contiguity of objects, and thus enabling it to avoid them.

Consciousness. — The animal functions, or functions of relation, are currently spoken of as the functions on which consciousness peculiarly attends. The states of consciousness are the various states of animal being in which the sense of existence is present. Thus every exercise of mind in man is properly described as a state of consciousness. All his sensations, emotions, appetites, and desires, are so many states of his consciousness; since the feeling of existence is an essential element in all these several affections. The exercise of locomotion, in obedience to volition, is a state of consciousness; and even involuntary acts, such as yawning, sighing, hysteric laughing, and the like, come under the head of conscious acts, or acts into which, as an element, the sense of existence enters. Hence, it may be inferred, that, in the lower animals, acts of pure instinct, altogether independent of anything like volition, are often states of consciousness. Thus man's animal existence is made up of a long succession of states of consciousness, scarcely altogether interrupted even during sleep.

The analysis and methodical arrangement of such states of con-
[illegible]usness constitute the proper business of the philosophy of the
[illegible]an mind. Of locomotion and the senses of animals we have
[illegible]dy briefly spoken; and, for the present, a few words must suffice
[illegible]nsation, emotion, reason, instinct, and thought.

[illegible]**ensation** is a mental feeling, or state of consciousness, to which,
[illegible]ever, certain corporéal preliminary conditions are essential.
[illegible] point of a needle makes the slightest puncture at the sur-
[illegible]in, a sensation takes place. The feeling of pain com-
[illegible] may speak, with a sense of existence, constitutes
[illegible]istinctly entitled to be termed a state of conscious-

ness. But there is also another element in such a sensation, which does not manifestly enter into every state of consciousness. That other element is, that the consciousness has a local seat; that the consciousness of pain is felt to exist at the point where the needle has pierced the skin. But anatomy quickly teaches us that the sensible point which the needle touches, is not the independent, although the manifested seat of sensation. It is found, that such a point of the surface of the body only remains sensible on condition that nervous filaments extend to it from the nervous centre, that is, from the brain or spinal marrow; that such filaments are entire and unbroken; and further, if they be divided, compressed, or otherwise seriously injured, that a needle may be thrust into the part without the production of any mental feeling whatever. In short, it is discovered by a little investigation, that when an impression, such as that made by a needle, affects the extremity of a nervous filament, a corresponding change occurs in the point of the brain, or spinal marrow, to which that nervous filament extends; and that this change in the nervous centre fails to occur, unless the nervous filament concerned be entire in its whole extent. The singularity here to be observed, is, that although the point in the nervous centre is plainly that on which the mental feeling depends, yet that that mental feeling is not felt to have any local existence, except at the extremity of the nervous filament touched by the needle. Thus the seat of sensation, the local seat of the state of consciousness, which constitutes a sensation, is always in the organ, or part of the body, where the nervous filaments concerned terminate. It is quite true, as Epicharmus sung:

> "Mind it seeth, mind it heareth—
> All beside is deaf and blind;"

nevertheless, the local seat of sensations is in the skin, the membrane of the nostrils, the membrane of the tongue, the labyrinth of the ear, the retina of the eye, and finally, in the locomotive organs in general, when brought into action.

The mind has, indeed, no local seat. It would be absurd to speak of a spiritual essence as having parts, or being in connexion with space; but, nevertheless, it is quite certain that in sensation the mind manifests itself in what are termed the organs of sensation. Here it is, then, in the skin and the other organs of sensation, that the confines of mind—so to speak—and the confines of matter meet. Nor is it erroneous to say that it is in sensation that mind communicates with matter. This view leaves the spirituality of the sentient principle wholly untouched. For, as Sir William Hamilton remarks (REID's *Works*, p. 862), "the connexion of an unextended with an extended substance, is equally incomprehensible, whether

we contract the place of union to a central point, or whether we leave it co-extensive with organization."

The notion of extension, or rather the capability of forming the notion of extension, is undoubtedly an original endowment of the human mind; but the realization of that notion, there is little reason to doubt, takes place as the infant gradually notes the variety in the local seats of the many sensations continually occurring in his consciousness. In short, as Aristotle taught, the infant's body is contained within his soul in the exercise of sensation.

Besides sensation, there are no other states of consciousness which have a manifest local seat, unless that it be said in a somewhat different sense of certain emotions. For, there are motions which are very constantly attended with certain bodily feelings, which feelings, on investigation, are discovered to be sensations arising during the exercise of certain muscular acts, which become, as it were, the signs of those emotions. All expression of emotion, whether calm or passionate, consists in certain movements of the locomotive system; and such movements of the locomotive system are attended, like the action of muscles in general, with sensations originating in the effect produced on the nervous sentient filaments of those muscles by the physical changes which they then undergo. Hence it appears that emotions themselves are not states of consciousness having a local seat; but that many emotions are accompanied by muscular acts which originate states of consciousness, or sensations having a local seat.

To such consecutive sensations, the name of sensations of emotion has often been given.

Emotion, in a larger sense, may include not only passions, but also desires, and, owing to their analogy with desires, even appetites. These constitute the impulsive part of human nature — leading to action too often with a vehemence overpowering all reason. All the bodily acts which result from emotions, passions, desires, and appetites, are doubtless attended with corresponding sensations; but, like those already mentioned, these localized states of consciousness are consecutive—not identical with these affections.

In proportion as man in society learns to control the impulsive part of his nature chiefly by the influence of reason, he advances in civilization. In the words of Ovid:—

"Et quod nunc ratio, impetus ante fuit."

Reason represents, collectively, the faculties, properly termed the Intellectual Faculties. Reason, however, implies the previous accumulation of knowledge, however slender, by comparison with that store of which man is capable. It has been well described as the action of the mind upon its knowledge. "Its power," says Isaac

Taylor, "over itself, a power directed by knowledge, and employed for the accomplishment of some purpose foreseen, is what constitutes reason." Reason, by the knowledge of the past, consults for the future, putting a restraint upon present impulses. Reason, by reference to what the memory can supply from the past, combines the means suitable to effect ends, and, not discouraged by repeated failures, changes and improves these means till the end is accomplished, as often as that is attainable. By reason, also, it is often determined that such and such ends are not attainable by the means actually within reach. Thus reason is not so much a single faculty as a power of combining the operation of all the intellectual faculties towards the attainment of the object in view.

The first men, beyond question, had no other shelter from the scorching rays of the sun, and the rains, and the blasts of heaven, than the woody thicket, or the natural caves of the rocks and mountains. To this day, near the banks of the Jordan, there are tribes who live in mountain caves. In Borneo there are races who live in trees, like monkeys. There are African princes who hold their audiences in Nature's own palace, under the shade of the gorgeous banyan. Let us suppose that a party of primitive men had strayed to a place affording the shelter neither of a thicket nor of the mountain cave, and that the heat of the sun, or the season of rains, caused them annoyance; then would arise the exercise of reason,—the first display of man's building talent. The inconvenience he suffers from the loss of his accustomed shelter, carries his thoughts back to the form of that shelter. Let us first suppose that his original shelter was a cave. It is not any inward impulse which leads him to fix poles in the ground, inclined to each other at the top for mutual support, and to cover these with the skins of animals he has killed for food, or with the large leaves and twigs he can collect around. But the desire to produce the likeness of his former cave raises a train of thought, in which are presented all such observations of his past life as bear on his purpose. The minute recollection of these stirs him on to the work, and, after failing and succeeding by turns, he at last, with repeated trials, constructs a rude tent, or hut, on the model which originally arose to his mind. It is by the imitation of what had before been seen that reason acts in such a case. In short, here it acts on the knowledge before accumulated, so as to apply it to the purpose in view. Here reason appears in its proper character; not as a single faculty, collateral with memory or imagination, but as the master of the faculties; that which controls and compels the subordinate powers each to contribute its proper share to the work.

Had the party referred to never seen a cave, but been accustomed to the shelter of trees, the first tent would necessarily take more of

the form of a tree; and were the model tree a banyan, we must suppose the tent would have been in the shape of a huge umbrella, supported at the circumference with slender posts, and in the middle by a stout pillar, corresponding to the central stem and descending roots of that singular production of the vegetable kingdom.

Instinct. — How different is instinct! Instinct is an agency which performs blindly and ignorantly a work of intelligence and knowledge. Many animals, particularly birds and insects, construct works to which, at first sight, there would seem to be requisite no small degree of forethought, knowledge, and calculation. In short, to produce such effects as are produced by many animals, an intimate knowledge of the principles of mathematics, and of the laws discovered by man in the physical sciences, would seem to be essential. Does any one believe that such knowledge and such faculties as are necessary for the construction of the honeycomb, reside in bees in the same sense in which it is said that such knowledge and such faculties belong to a man who is possessed of them? "It would take," says Sidney Smith (*Moral Philosophy*, p. 243), "a senior wrangler at Cambridge ten hours a-day, for three years together, to know enough mathematics for the calculation of these problems, with which not only every queen bee, but every undergraduate grub, is acquainted the moment it is born."

It is not, however, sufficient, with Isaac Taylor, and many other authors, directly to impute the knowledge and the forethought to the Creator; because we are required, in studying such a subject, to consider all the laws regulating such acts in the organic kingdoms, and endeavour to ascertain, before such a direct reference is made to the power of the Creator, how far the instincts of birds and insects, by which so many wonderful effects are produced, are not merely a part of a larger law which operates in that part of nature as a whole. The final reference, of course, is to the power of God, whatever be the result of our inquiries.

It is now many years since it was observed, in man and animals, in general, that certain impressions made on the organs of sense, or on sensible parts of the body, are succeeded by muscular acts, sometimes of a very complex kind, performed altogether independently of the will. It was not at first observed, that on many occasions impressions might be made on many parts of the body, such as give rise to complex muscular acts of this kind, not only indepedently of the will, but even without any consciousness on the part of the individual that such impressions had been applied. Such, however, is the case. The nervous system is so constituted that certain impressions made on the extremities of nervous filaments, terminating chiefly on the surfaces of the body, are succeeded by the determination of influences, through other nerves, to muscular organs, by

which these organs undergo movements on a definite plan, and often of a very complex kind. When no consciousness attends the impression, so that the affection of the nervous centre thereby produced fails to possess the character of a sensation, the effect is what gave rise to the idea of reflex actions, not accompanied by sensations, having their origin in the spinal marrow, in which plainly resides the power of determining certain complex muscular acts, on being affected by impressions conveyed through certain means. But all such muscular acts as originate in impressions made on the extremities of nervous filaments, independently of volition, whether accompanied by consciousness of the impression, or unaccompanied by such consciousness, are conveniently termed reflex acts.

This view of the nervous system in higher animals, for which we are chiefly indebted to Dr. Marshall Hall, though it does not explain, serves very much to illustrate the nature of instinct. According to the expression of a distinguished physiologist, Prochaska, "Peculiar laws are written, as it were by nature, on the medullary pulp;" and such and such impressions, conveyed by nerves to the nervous centre, whatever it may be, in the animal, call forth particular acts, in obedience to such originally written laws.

In short, the various acts of instinct in birds and insects, according to this view, present no greater difficulty, or, at the most, one not very much greater, than the numerous reflex acts subservient to the well-being of the body, varied as these constantly are in man and animals, under successive changes of circumstances. Such acts, and instinctive acts, fall under the same great law of the nervous matter — a law unquestionably originally impressed upon it by the fiat of the Creator. "As, then," says Dr. Bushnan (*Philosophy of Reason and Instinct*), "certain organic acts are the direct effect of sensation, so it will be found that instinctive acts, properly so called, can be traced to the same cause, and are, like them, dependent either on external or internal stimuli." The great sources of instinctive acts in the lower animals, are the senses of smell and taste; by which, particularly the former, they are led to select food which is salutary, with a certainty which far exceeds the boasted knowledge of man. There is scarcely a plant which is not refused by some, while it is eagerly sought after by others; and as many of these plants are highly poisonous to man, we must here draw the striking conclusion, that when the instinct of an animal leads it to eat of a plant poisonous to others, the law which so directs it, through the unconscious nervous centre, must embrace the fact that the poisonous chemical principle of that plant is destroyed by the peculiar digestive power of that animal.

Finally, among the sources of sensation on which instinctive acts are dependent, are various qualities of the atmosphere at different

seasons, the periodical returns of appetites, and particularly of the sexual desire, the sense of ungratified want, the consciousness of muscular action, and, in higher animals, the presence of all kinds of emotion.

Thought.—When spoken of in connection with the functions of relation, Thought has an extensive signification. It is then contrasted merely with sensation; so that sensation and thought are often employed to include all mental phenomena. Such a use of the term thought, is, however, merely for the sake of temporary convenience; since emotions, passions, desires, and appetites — all of which are states of consciousness, distinct from sensations, can with no propriety be deliberately regarded as thoughts. If, however, from the whole succession of a man's states of consciousness we subtract his sensations, his emotions, his passions, his desires, and his appetites, then those states of consciousness which remain, will be such as are most appropriately termed thoughts. Thus, then, an act of memory is a thought; an act of conception is a thought; an act of abstraction is a thought; an act of imagination is a thought; an act of judgment is a thought; — and to think is specially to determine, with some definite purpose, successions of these several kinds of acts.

When a person thinks over a subject, he puts it in all possible lights, endeavouring to find out each new relation in which it stands; — that is, making use of what he has observed as to the modes in which one thing suggests another, he makes those things which rise spontaneously in his mind, the means of bringing up other things which were less obviously connected with his first thoughts.

Thinking, then, is a succession of acts, only in part voluntary. A man cannot call up any thought at pleasure unless within very narrow limits. But when he has once got possession of a thought, by dwelling on it, and considering its several connections, he may be secure that it shall arise whenever certain other thoughts shall have first occurred to his mind. When a man thinks correctly on any subject, it is very much the same as to say he exercises reason on that subject. For, to think correctly, he must exert a certain control over his thoughts, rejecting those which are vain, frivolous, and not pertinent to the subject, and detaining those in the contrary predicament. Still the mere expression *to think* has no constant reference to the exercise of reason; since one may be said to think in the larger sense when the thoughts suggested to the mind by some subject rise freely, whether they be to the purpose or not. Thus it is quite correct to say, that a man thinks incorrectly; and in so thinking he may have exercised actually as much voluntary control over his thoughts, as in any profound and just meditation. But to

say that a man exercised his reason incorrectly, involves a contradiction. Thus, to think and to exercise the reason, are not one and the same thing. The reason, indeed, cannot be exercised without thinking; but much thought may pass through the mind with very little exercise of reason.

What is commonly called a train of thought presents this term in its widest signification. We say currently a train of thought is dependent on the association of ideas. But, when a train of thought is reviewed—for example, such a train as constitutes a reverie—it is found to consist not merely of the states of consciousness commonly called thoughts, or of those expressed by the term ideas, but of states of consciousness of every known kind—sensations, memories, abstractions, conceptions, imaginations, judgments, pity, remorse, anger, jealousy, ambition, desire. And each of the states entering into such a train is linked or associated with the states adjacent to it in the succession; so that what is usually called the association of ideas, is really the order in which the succession of every kind of consciousness happens at any one time to be determined.

Every man has his trains of mental phenomena, to a certain extent, under his own power, and this is the foundation of all self-education, or rather the foundation of all moral and intellectual education. It is quite possible that a child may be so reared as to be incapable of conforming the conduct of after life to the standard of morals required by the laws of his country. This person is exactly in the condition of him who labours under moral insanity. Had the dispositions, in childhood, of such a person been restrained by judicious management, then the passions, desires, and appetites would have been reduced within those bounds which reason requires. When the natural disposition is such that, under the best direction, a child grows up totally incapable of subjecting his moral nature to the control of reason, then that person is morally insane from birth.

The intellectual nature is perhaps less under the control of management than the moral nature. Nevertheless, education is capable of greatly extending the range of thought, and, within somewhat narrow limits, of giving to it greater justness and exactness than naturally belongs to the individual.

The benefits of training, whether by the education imparted from without, or by the efforts of the individual himself towards self-improvement, are manifestly dependent on the changes accomplished on the natural succession of the states of consciousness, or, in common language, on the natural succession of thoughts. And it is manifest that the more any one has indulged in incorrect thinking, or in licentious wishes, before the corrective of training is applied, the more difficult it must be to bring back the current of his intellectual and moral nature to that which reason directs. Correct

thinking, intellectually and morally, is the only foundation of just judgment and blameless conduct: —

> ——————— "For since the course
> Of things external acts in different ways
> On human apprehension, as the hand
> Of nature tempers to a different frame
> Peculiar minds; so, haply, where the powers
> Of Fancy neither lessen nor enlarge
> The images of things, but paint in all
> Their genuine hues the features which they wore
> In nature — there opinion will be true,
> And action right."—AKENSIDE.

The next and last function we have to consider is that of speech, or the sounds which are produced in the larynx or vocal apparatus at the moment when the air traverses this organ, either to enter or to pass out of the trachea, or windpipe; and we shall distinguish speech in man from the cries, song, and buzzing of inferior animals.

Voice.—Without the possession of voice how different would have been the history of man's progress on the earth! We can hardly conceive any other effectual kind of speech except that to which voice is subservient. Without articulate sounds man could hardly have risen to the rank of an intelligent thinking agent. By means of expression and gesture he might have communicated to his fellow-men no small share of his present desires, his present feelings, and even his present rude ideas; but under such circumstances how little of the past—how little of the future—would have entered into his mental existence!

Speech, then, may be justly regarded as one of the principal foundations of man's greatness upon the earth; and thus voice, speech, the cries of animals, the song of birds, and the buzzing of insects, present, in a physiological point of view, a succession of themes of the most engrossing interest.

In physiology voice is distinguished from speech, though without voice there is no perfect speech. This point deserves a word of explanation. When a person can speak only in a whisper, he is said to have lost his voice; that is, he has lost the power of utterance with that loud, thrilling, vibratory sound which constitutes perfect voice. But if whispering were man's only natural mode of speech, then we should not be entitled to say that man had no voice, but only that his voice was a soft, hissing, non-vibratory sound.

Voice, then, whether it be soft and hissing, or loud and vibratory, is formed in the larynx. Speech is the voice modulated in its passage through the mouth and nose by the agency of particular organs, such as the tongue, the palate, the teeth, the lips. It is conventionally only, and for the sake of convenience, that physiologists

speak of a whisper as being speech without voice, that is, without vibratory voice; and of those who speak only in a whisper, as having lost their voice, in contradistinction to those unfortunates who suffer under a loss of speech, which properly constitutes dumbness.

Dumbness originates exclusively from original defect of hearing—thus indicating the intimate connexion between the gift of articulation and the perfection of that sense. Again, the capability of the dumb (deaf-mutes, as with something akin to an affectation of precision they are now often called) to acquire the use of speech, rude as it commonly is, shows how largely the organs concerned are placed under the control of the will.

The Sources of Sound.—The organs of the voice and of speech are analogous to instruments of music, so that some preliminary observations on the sources of sound become requisite.

In every case sound is derived from the vibration of a body. It is, however, erroneous to describe sound as merely a vibration of the air. Most sounds, it is true, reach the ear through the vibration of the air, whether they have had their source in the air, or in some body with which it is in contact. It is usually said, that a bell has little or no sound in a vacuum. This is in so far true; for unless a communication is made between the ear and the bell independently of the air, little or no sound would be heard. But if a cord or some similar body be stretched between the bell and the ear, and particularly if the external cavity of the ear be previously stopped with some substance, such as chewed paper, which the cord is made to touch, the sound of the bell will be distinctly heard. In such a case no part of the communication of the vibrations of the bell is made through the air—the membrane of the tympanum or drum of the ear receives the vibrations and transmits them through the chain of little bones to the labyrinth or most interior part of the ear, where, by means of undulations excited in the fluid in contact with the subdivisions of the auditory nerve, the requisite impression is made.

Many other instances may be cited of sounds produced by the vibrations of solid bodies being conveyed to the ear without the intervention of the atmosphere. For example; when a tuning-fork is made to vibrate and placed between the teeth, the sound is conveyed from the teeth, through the bones of the face and the head, to the auditory nerve. Also when a solid-vibrating body is suspended by a cord which is brought into contact with the teeth, the sound is heard independently of the atmosphere. Again, when a sounding body is suspended between two cords reaching to the ears, the influence of the air is excluded. When a cord is extended from a sounding body to some part of the head, particularly to such parts as are sparingly covered with soft substance, the sound is heard

without the assistance of the atmosphere. When a watch touches the teeth, particularly of the upper jaw, its ticking is distinctly heard on the same principle. When the watch is applied to the tongue, the sound is much fainter. We find it stated that the vibrations of a metallic spoon were heard at the distance of three hundred yards by means of a cord extended to the ear. We are told that the sound of distant cavalry is heard much better when the ear is applied to the ground than when the listener stands erect. In cases of this kind, where the sound is conveyed along the surface of the ground, it is to be understood that the sounds are produced in the ground itself, or in the solid bodies communicating directly with the ground.

Vibrations are also communicated from water to the ear without the assistance of the atmosphere. For example; in bathing, when the head is plunged under water, distant sounds produced in the water are heard distinctly. When, however, sounds proceed from water into air, the effect produced on the air is faint.

The sounds which reach the ear through the atmosphere may originate in vibrations of the air itself, or may have been communicated to it by the vibrations of liquid or of solid bodies. And this, doubtless, is the common case. Nevertheless, it is plain, from what has been above stated, that to describe sound as a vibration of the air is to view it in too limited a sense.

To produce sound the vibrations must be of a certain strength; for it is plain that a body often continues to vibrate after it has ceased to emit sound. Sounds pass through air with less rapidity than through water, and through water with less rapidity than through solid bodies. For example; the sound of a hammer struck at the top of a high house is heard double by a person standing on the ground below; that is to say, the first sound which reaches his ear is conveyed through the solid materials of the house, while the second sound is transmitted through the air to his ear. It is observed, also, that on the approach of a heavy wagon in the street the furniture of a house begins to shake before the noise of the wagon is heard.

The velocity of sound in air is estimated at 1130 feet per second—in water at 4708 feet in the same unit of time. The velocity of sound conveyed through solid bodies appears to vary much according to the texture of the substance. From some experiments, it appears to pass through deals of fir-wood at the rate of 17,400 feet per second, which is upwards of three miles.

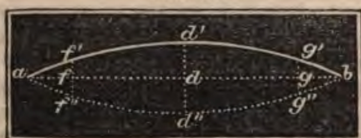
When a sound is produced in an open space, it is more short and sharp than when in a room; because, when a sound occurs in a room, the vibrations of the air which strike against the walls and furniture excite new vibrations in these bodies, which, being again

communicated to the air, affect the ear in close succession with the original vibrations, and so prolong the sound. This effect is termed the reverberation of sound. When there are no bodies near at hand to reverberate the sound, but a body or bodies at a distance capable of that effect, an echo is produced. Thus an echo may be described as a reverberated sound, which does not reach the ear until the primary sound has ceased. An echo may take place from a wall, a rock, a grove of trees, and, as it is said, even from a cloud; and also, as it would seem, from condensed air. If an echo can take place from a cloud, it is an example of an echo produced by the vibrations of water in its liquid state. The body from which a distinct echo takes place must be at a considerable distance, and there must be no interposed bodies capable of keeping up the succession of vibrations. In every large and lofty empty room there is a species of imperfect echo, owing to the want of furniture to keep up the successions of reverberations between the termination of the primary sound and the reverberations from the walls and roof. The echo of a monosyllable requires a less distance than the echo of a dissyllable; it is estimated that the distance required for a monosyllable is 80 feet, that for a dissyllable 170 feet.

A musical sound is to be distinguished from a noise. A noise consists either of a single powerful concussion or report, or else of an irregular repetition of such sounds. A musical sound consists of a number of synchronous vibrations; that is, of vibrations occupying the same minute period of time. The vibrations in a musical sound are not all of the same extent; but whether great or small, each occupies the same period of time — in short, they are like the vibrations of a pendulum, which, whether great or small, are performed in the same space of time, when the pendulum is of a definite length.

Sonorous undulations may be described as of two sorts — namely, curved and molecular. We have an example of curved undulations when a string, *f d g*, fastened at both ends, *a b*, so as to be tight, is drawn to one side at its middle point. By this retraction the string, which was before straight, is now bent into a curve, *a f′ d′ g′ b*. When let go it not only recovers its former position, but passes to the other side, assuming the same curved form, *a f″ d″ g″ b*, into which it was at first drawn; and thus it continues to vibrate from side to side, alternately forming a curve, with a gradual diminution of extent on each side of its original position. So long as these vibrations are of considerable

Fig. 81.



strength, a sound is emitted; but, as before observed, the sound ceases before such a string returns entirely to rest. To produce an impression on the ear, but a moderate velocity in the vibrations is necessary. It appears that a sound may remain audible with a velocity of no more than $\frac{1}{100}$th part of an inch in a second: perhaps it may be heard even with a much smaller velocity than this. Nevertheless, in such a case it is probable that the initial velocity must be considerably greater than that here described.

What is termed molecular undulation is exemplified in the alternate condensation and rarefaction of air. When we blow into a

Fig. 82.

tube open at both ends, the air contained first becomes condensed in the middle, and rarefied at the two extremities, as seen by the

Fig. 83.

lighter shade in the cut; but after a while the case is reversed, the rarefaction being in the middle, the condensation at the extremities.

What is termed difference of tone depends upon the number of vibrations in a given period of time. When the number of vibrations is small, a grave sound is produced; when the vibrations are numerous in the same time, an acute sound is heard. Their thickness being equal, a long string produces fewer vibrations than a short string in a given time. Thus, by lengthening a string, the tone of a musical sound produced by its vibration passes from the acute to the grave. When the quality of a sound is spoken of, it has no reference to the number of vibrations in a given time, quality being dependent on the molecular constitution of the sounding body. From what has been already said, it must be seen that the mere extent of vibrations does not affect the tone. It appears, however, that loudness of sound is dependent chiefly on the extent of the vibrations.

Musical sounds, then, are produced either by the vibrations of solid bodies, of liquid bodies, or of aëriform bodies, or by a combination of the vibrations of two or more of these.

There are even musical instruments, or musical combinations pro-

duced by solid bodies, independently of any musical tension. For example, melody may be extracted from cylinders of glass, or of metal, struck either directly or by means of keys — the tuning-fork, the gong, the cymbal, the bell, are examples of the same kind. The harmonica consists of a series of glass vessels made to yield musical sounds by the friction of the fingers. But the most important case of this kind, as bearing on the explanation of the phenomena of the voice, is the vibration of an elastic plate produced by a current of air which it continually emits and excludes. Such a plate is employed in those forms of the organ-pipe which have been termed the *vox humana pipe*, and regal pipe. The vibrations of water are hardly employed to produce musical sounds; nevertheless, the purling rill and the distant cataract plainly fall within the description of musical sounds.

In simple wind-instruments of music, we have examples of musical sounds produced by molecular undulations of air: in the flute, the flageolet, the diapason organ-pipe, the humming-top, the cavity of the mouth in whistling, and playing on the Jew's-harp, the molecular undulations of the air are the sources of the musical sounds. In the flute and flageolet the length of the tube is altered at pleasure by opening or shutting the holes. When a hole is opened it is the same thing as if the pipe were cut off a little beyond the place of the hole.

In many musical instruments the vibrations of solid bodies cooperate with the undulation of the air to produce the musical sounds. This is the case in the trumpet and in the various kinds of horn. In these instruments, the force of the inflation produces what are termed harmonic divisions. The trombone is so contrived that the length of the tube may be altered at pleasure. In what are termed the reed pipes of an organ, there is an elastic plate which vibrates in unison with the column of air which they contain. The vibrations of animal membranes, when put on the stretch, as a source of musical sounds, are usually considered separately, both from the sounds produced by solid bodies and those produced by the molecular undulation of air. There are examples of this effect of those membranes in the use of such instruments as the drum and tambourine. These instruments are chiefly prized for their loudness. Under the same head, however, falls the membranous tongue, which bears closely on the illustration of the human voice. What is here referred to is not, indeed, a musical instrument, but a contrivance employed to exhibit the effects of sound under circumstances analogous to those of the human larynx. The most remarkable experiment of this kind is made by placing two thin plates of India rubber over the end of a tube, so as to leave a very slender fissure between their margins in the middle line, and fixing these by a liga-

Fig. 84.

ture. Two pieces of leather employed in the same manner produce a similar result. When two such tongues or membranes are placed over the orifice of an organ-tube, and the current of air made to rise through it, vibratory motion is maintained by this current, and a considerable range of musical sounds is produced. The two tongues or membranes in this experiment should be in the same place, and the space between them should be very minute: the edges of the tongue should not be farther apart than from $\frac{1}{12}$th to $\frac{1}{10}$th of an inch. The experiment succeeds even better when the edges actually touch. To this experiment reference will be made hereafter, when we come to speak of what occurs in the human larynx during the exercise of voice.

Organs of Voice and Speech in Man. — The organs concerned in voice and speech may be described as the chest and lungs, the windpipe, the larynx, the posterior cavity of the mouth, the nostrils, which communicate with that posterior cavity, the palate, the tongue, the teeth, and the lips. The sounds which constitute voice belong to the order of musical sounds, independently altogether of the singing voice. All that is properly termed voice takes place in the larynx, which is properly the instrument of voice. But even independently of the modifications by which voice is changed into articulate speech, the voice is variously affected by the other parts which have been enumerated: by the chest, as regulating the force of the air; by the windpipe, as susceptible of several degrees of length and tension; by the posterior cavity of the mouth, as offering an expanded vault; by the nostril, as affording a double passage of exit for the breath; and by the various conditions of the tongue, the palate, the teeth, the lips, according to the position in which they happen to be at the moment.

The chest and lungs together constitute, in reference to the voice, a musical bellows, capable of supplying air with more or less force to the organs of voice The peculiarity of these bellows consists in the fact that the air must be renewed, at short intervals, by entering from without by the same passage by which it is expelled when the voice is exercised. It can, however, supply air without interruption, in a continued stream, for about fifteen seconds. The lung consists of two large bags of air, and does not materially differ from the windbox of an organ, or rather from the bag of a bagpipe. No air can enter the lung, or escape from it, except through the windpipe. The walls of the chest are everywhere in contact with the outer surface of the lung, and close in around the point at which the windpipe rises upwards to the larynx. The chest is capable of expansion in every direction; that is to say, by means of muscular action its walls

recede from the surface of the lung, so that the cavity in which this air-bag is contained, is augmented in every direction,—in length, in breadth, in depth. Whenever this enlargement commences the air begins to enter from without. By this process, in two or three seconds, many cubic inches of air can be drawn into the lungs. So nice is the action of the muscles, by which the chest is again contracted in size, and the lung is compressed, that the stream of air which shall issue in a given period through the larynx, by the influence of the will, is under the most complete control. The prominence of the larynx on the fore part of the neck is popularly known by the name of Adam's apple, by which, probably, its remarkably greater prominence in the male than in the female is referred to. The long succession of minute tubes, by the gradual union of which the other trunks, and finally the windpipe, are formed, has this peculiarity, that the aggregate of the areas of the smaller tubes greatly exceeds the area of the trunks which they combine to form. From the windpipe throughout, almost to their origin in the minute cells,

FIG. 85.

FIG. 85.—*a*, basement or cricoid cartilage resting on the cylindrical windpipe; *b*, projecting cartilage or thyroid cartilage; *d*, valve-like cartilage or epiglottis.

FIG. 86.

FIG. 86.—*c c*, Pyramidal or arytenoid cartilages; *a*, cricoid or basement cartilage; *e e*, the tongues or proper vocal cords, called also vocal ligaments, also aryteno-thyroid ligaments and inferior vocal ligaments; *f f*, the ventricles of the larynx; *d*, the epiglottis.

the tubes are provided with tense walls, by means of the cartilaginous appendages before referred to; in the windpipe itself these cartilages assuming a more definite form. They are in complete rings of cartilage, being deficient posteriorly, that is, each ring of

the windpipe traverses about two-thirds of its circumference, leaving the remaining one-third, on its posterior aspect, destitute of this support. The number of rings in the windpipe is from fifteen to twenty; in other respects the tube is chiefly membranous, yet provided with muscular fibres capable of diminishing its calibre, by drawing together the extremities of the rings. It has been proved, by sufficient experiments, that when the larynx is raised by the powerful muscles attached to it, the windpipe is drawn up from the chest in a corresponding extent, and that at the same time its diameter is diminished by about one-third.

The base, or lowest part of the larynx, rests on the upper part of the windpipe, and this base consists of a ring, somewhat more developed than any of the rings of the windpipe, yet not so different from these but that it might be regarded as the summit of that tube. This ring differs from the rings of the windpipe in being complete all round; it is not, however, of a uniform breadth in the direction from below upwards, being broader at the posterior part. It may be likened, then, to a ring, with a stone or a seal, the expansion behind corresponding to the stone or seal. On the upper edge of the expanded portion of this ring, at the base of the larynx, are set two slender bodies of a pyramidal form, which bear the most important part in the mechanism of the larynx as an organ of voice. These two bodies are exactly alike, and are placed almost close together, like two miniature obelisks set on end. The connection of their inferior extremities with the basement ring of the larynx, is by articulation, viz., by a true joint, like the shoulder-joint; that is to say, they are movable on the cartilaginous ring which supports them. From the one to the other, on their posterior aspect, muscular fibres extend, by the contraction of which these two minute pyramids are made to approximate together. From the fore part of each, near their bases, an elastic substance proceeds forwards, converging, to interlace with its fellow at the anterior part of the larynx; that is to say, a minute somewhat triangular space is formed by two portions of elastic tissue, which cross the basement ring of the larynx from behind forwards, the base of this triangle being the space between the two pyramidal bodies just spoken of and its apex behind, a portion of the larynx to be presently alluded to. This triangular space between these two portions of tissue, vocal ligaments, as they are called, is the aperture by which the breath enters and issues in respiration, and by which, when contracted to a narrow chink, the air is forced through in the exercise of voice. These, then, are the most essential parts of the larynx; the two pyramidal bodies each resting on the posterior part of the basement ring, while the two ligaments proceed forwards, each from the base of one of these pyramids, to form a triangle, the apex of which is so directed as to

be over the anterior part of the aperture of that basement ring. It is manifest that when these two minute pyramids are drawn close together by the action of the muscular fibres, the base of the triangular opening is diminished, so that the posterior or wider part of the opening becomes obliterated; also, if the apex of this triangle be drawn forwards, that the sides formed by the two vocal ligaments will still further approximate. Such, then, are the two actions by which the triangular aperture is reduced to a minute chink, namely, by the points to which its base is attached being made to approximate, and its apex being drawn forwards.

Other muscular fibres are so disposed as to antagonise the forces which close the aperture; two sets of fibres on each side extend from the basement ring inwards, to be attached to the pyramidal cartilages, by which they are drawn asunder, and the base of their rectangular aperture again restored to its former extent.

Several important, yet less essential parts of the larynx, remain to be described. The anterior narrow part of the basement ring supports that great prominence which constitutes Adam's apple. This is by far the largest portion of the larynx, but may be regarded merely as a defensive plate guarding the essential parts of the organ from injury. When the finger is placed upon its upper margin, and directed a little upwards, a hard, wire-like circle is felt; this is the convexity of the hyoid bone, or bone of the tongue, which has intimate connections, by ligaments and muscular fibres, with many adjacent parts, so that it is rendered, as it were, a centre of motion. Hence, when the hyoid bone is raised, many of the adjacent parts follow its movements. The hyoid bone is described as having the shape of the Greek upsilon, the convexity being directed forwards, and to be felt immediately above the great cartilage of the larynx. This great cartilage, then, termed the thyroid cartilage, may be described as a quadrilateral sheet of cartilage, with appendages at its four angles, named its cornua, or horns. This quadrilateral sheet is bent along its perpendicular middle line, and this bending constitutes the angle which is felt in Adam's apple; the upper horns are attached to the hyoid bone, the under horns to the basement ring before spoken of. Thus the thyroid cartilage is wrapped round the essential parts of the larynx, in front covering them in, leaving them exposed behind. The prominent angle in front corresponds to an interior angle on its posterior aspect; and to the middle part of this interior angle extends the apex of the triangle formed by the vocal ligaments, and there obtains an attachment.

A movable valve, like a little tongue, its apex directed backwards, is attached to the same interior angle of the protecting cartilage, a little higher up, overhanging the cavity of the larynx. Between the same interior angle of the anterior protecting cartilage, and the

two movable posterior cartilages before described, muscular fibres proceed, by the contraction of which those triangular movable cartilages are drawn forwards, so as to relax the elastic cords, already termed vocal ligaments. From the same interior angle of the protecting cartilage, an elastic substance proceeds, radiating in different directions, so as to close in the parts otherwise unoccupied above the lateral portions of the basement ring of the larynx. This elastic substance, in particular, forms two cords, extending between the superior points of the movable triangular cartilages and the sides of the tongue-like valve before spoken of. These cords constitute what have been termed, somewhat improperly, the superior vocal ligaments. When the space beneath these so-called superior vocal ligaments and the true vocal cords, or vocal ligaments, is examined, a cavity is found on each side of considerable extent; and the two cavities are called the ventricles of the larynx. The mucous membrane, descending from the mouth and nostrils, covers and forms a lining to these parts in its passage downwards into the windpipe and lungs; so that the so-called superior ligaments of the larynx are often described as mere folds of the mucous membrane, extending between the posterior pyramidal cartilages and the protecting cartilage. It appears, however, from more minute investigation, that these folds of the mucous membrane do actually contain an elastic substance, not less capable, under certain circumstances, of vibratory action than the true vocal cords, or true vocal ligaments.

FIG. 87.

a, the cricoid; *b*, the thyroid; *d*, the epiglottis.

To recapitulate, then, the prominent points in the conformation of the larynx—the windpipe, called by anatomists the trachea, is surmounted by a complete cartilaginous ring, about an inch in diameter. This ring is the only outlet of the lungs by which air can issue from their numerous cavities, and is the only inlet by which air can penetrate from the atmosphere into the same cavities. This ring, being of a firm cartilaginous structure, is plainly incapable, under any ordinary circumstances, of dilatation and contraction. But the air is permitted neither to pass inwards, nor to come forth through the whole area of this cartilaginous ring, whether in respiration or in the exercise of voice. Its area is closed up on each side by impervious texture, so as to permit a passage to the air only by a chink, variable in its size, extending in the direction of its antero-posterior diameter. This chink is bounded, according to the common descriptions, by the vocal ligaments. It is more accurate to say

that this chink is bounded in its anterior part by the vocal ligaments, one on each side, and at its posterior part by the cartilaginous processes of the base of the movable pyramidal cartilages to which these cords are connected. This chink, when most expanded lengthways, is about eleven lines in length, and of this space seven lines lie between the vocal ligaments, and four between the opposite cartilaginous bases of the pyramidal cartilages, above spoken of, to which anatomists give the name of arytenoid. This chink, as above stated, is usually described as triangular, with its base between the two arytenoid cartilages, and its apex attached to the anterior angle of the protecting cartilage, above spoken of, to which anatomists give the name of thyroid. More correctly, at its greatest dilatation, it has a lozenge shape, with the posterior angle truncated. Thus the chink commences narrow immediately behind the thyroid cartilage, expands between the vocal ligaments to their attachment at the base of the arytenoid cartilages, and then contracts in the space between the cartilaginous bases of these two bodies, not to a point, but to a truncated angle. The widest part of the chink, in its greatest state of dilatation, is about five lines and a half—nearly half an inch. This greatest degree of dilatation takes place during inspiration; during expiration, the chink undergoes a slight contraction. But during the exercise of voice, the posterior part, bounded by cartilaginous margins, as being between the base of the arytenoid cartilages, is entirely obliterated. Thus it is correctly stated, that the chink, concerned in the exercise of voice between the true vocal ligaments, at its greatest dilatation, is of a triangular shape, being entirely bounded on the sides by the vocal ligaments, and its base corresponding to the points between their attachment to the arytenoid cartilages. As before stated, the arytenoid cartilages are attached to the upper surface of the posterior part of the basement cartilage of the larynx, or cricoid cartilage; and the vocal ligaments being attached to the bases of these arytenoid cartilages, it is manifest, that when these cartilages are drawn together, the vocal cords must approximate; that when they are drawn asunder, the vocal cords must recede from each other at their posterior part; that when the arytenoid cartilages are drawn backwards, the vocal cords must be put on the stretch; that when the thyroid cartilage, to the interior of which the apex of the triangle, formed with the cords, is attached, is drawn forwards, they must also be put on the stretch. All these changes are known to occur by the action of particular sets of muscles. The thyroid cartilage, which forms "Adam's apple," is connected to the basement, or cricoid cartilage, by an elastic membrane, which of itself tends to keep the thyroid cartilage nearly in the same perpendicular line with the cricoid, so as, in some degree, to stretch the vocal ligament. But there are two

muscles extending between the cricoid cartilage and the thyroid, by which the thyroid cartilage is drawn forwards, so as distinctly to stretch the vocal ligaments. There are also two muscles extending between the posterior part of the cricoid cartilage and the posterior surface of the arytenoid, by which the arytenoid cartilages are drawn back. These two pairs of muscles, when they act concurrently, must very much stretch the vocal ligaments. A set of muscular fibres, before spoken of, passing between the arytenoid cartilages on their posterior aspect, by their contraction causes the cartilages to approximate. Two other muscles, extending from the sides of the cricoid cartilage to the arytenoid, draw them asunder. Some other muscular fibres are found connecting the cartilages of the larynx; but the account of these, owing to their less importance, may be omitted.

The small muscles of the larynx are represented in the annexed figures. The crico-thyroidei (*b*, fig. 88, *a*, fig. 89), and the crico-arytenoidei postici (*b*, fig. 89), extend the vocal cords in the direction of their length, and, at the same time, narrow the glottis. The crico-arytenoidei laterales (*c*, fig. 89), and the thyro-arytenoidei (*d*, fig. 89), rather relax the vocal cords. The oblique and transverse fibres of the arytenoideus (*e* and *f g*, fig. 89) close the posterior half of the glottis. The epiglottis (*K*, fig. 89) forms a valve, which can be brought over the glottis by fine muscular fibres attached at *b* and *i* (fig. 89).

Fig. 88.

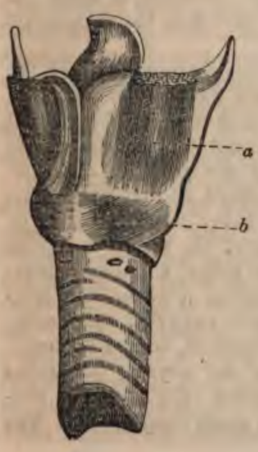
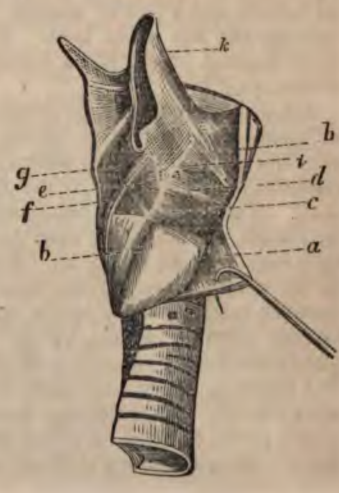


Fig. 89.



Such, then, are the parts of the larynx which must be explained to render the phenomena of voice intelligible.

The larynx, like other organs of the body, is largely supplied with blood by the common blood-vessels. Two nerves on each side are devoted to the actions of the larynx. These nerves are from the eighth cerebral pair: the superior laryngeal nerve is expended chiefly on the mucous lining of the larynx; the inferior laryngeal nerve, derived from the recurrent of the eighth pair, sends minute filaments to the several muscles concerned in the movements of the larynx.

Besides the movements of the component cartilages of the larynx on each other, attention must be paid to the motion of the whole larynx upwards and downwards. This motion takes place constantly in the act of deglutition, but also on many occasions when the voice is exercised, particularly in singing. When the whole larynx is raised, the windpipe is drawn proportionately upwards from the chest, and so put on the stretch. This movement has unquestionably some effect in extending the compass of the voice. It was before stated that the hyoid bone is connected to the protecting cartilage of the larynx, and that when this bone is drawn upwards, the larynx is drawn upwards along with it. The hyoid bone is drawn upwards by muscles attached in particular to the lower jaw, and also to the temporal bone of the skull. The hyoid bone is drawn downwards by muscles attached to the superior part of the breast-bone and to the shoulder-blade. From the upper part of the breast-bone a pair of muscles ascends, to be attached to the thyroid cartilage of the larynx, and a pair of muscles also extends between the thyroid cartilage and the hyoid bone. Thus ample provision is made for the movement of the whole larynx in concert with the movements of the hyoid bone.

A few words must next be devoted to the cavities through which the air passes outwards after issuing from the larynx. Behind the larynx is the cavity of the pharynx, situated in front of the cervical vertebræ, and ascending to the inferior aspect of the base of the skull. This cavity, not improperly termed the posterior cavity of the mouth, communicates with the nostril above, and on either side, by a narrow canal, called the "Eustachian tube," with the cavity of the drum of the ear. This posterior cavity of the mouth is divided from the anterior cavity by the veil of the palate, a musculo-membranous movable curtain, which by its motions more or less completely divides the anterior from the posterior cavity of the mouth. The movable, tongue-like valve, before spoken of, termed by anatomists the epiglottis, overhangs the orifice of the larynx; the arches of the palate descend on either side, possessed of a muscular character. From the union of these above the uvula hangs down. The

tongue, free and movable in its anterior part, forms the floor of the whole passage between the root of the epiglottis and the incisor teeth of the lower jaw. The muscular mass forming the cheeks contracts the cavity of the mouth on the sides, and the lips by their mobility variously modify the aperture by which the air issues.

Thus the air issuing from the larynx may pass out either by the nostrils or the mouth. It passes out by the nostrils when the mouth is closed, or even when the veil of the palate descends. When the veil of the palate is raised, and the mouth is opened, a free passage is afforded, through what has been called the oral canal, outwards. The oral canal is manifestly capable of much greater modification as to size, than the passage of the nostrils.

"The tongue, the lips, articulate; the throat,
With soft vibration, modulates the note."—DARWIN.

On the Human Voice.—In the investigation of the human voice, two points in particular deserve attention—first, the inquiry into the precise seat of the sounds; and secondly, into the mode in which these sounds are produced.

As to the first question, it is now determined, beyond all doubt, that the sound of the voice is generated in the glottis, and neither above nor below that point. Before going further, it should be remarked that this word glottis has not always been used in exactly the same sense. "By turns," says the eminent French physiologist, Adelon, "the superior aperture of the larynx, its inferior aperture, and the intermediate space between these two apertures, has borne the name of glottis; but, according to the etymology of the word, derived from γλωσσα, the tongue, the speech, no other part of the larynx should be called by that name but that where the vocal sound is formed—and we shall see that that part is the inferior aperture or chink."—*Physiologie de L'Homme*, ii. 256. In this sense alone, then, the word glottis is here employed, namely, to signify the aperture between the two vocal ligaments, that is, between the two inferior vocal cords, as they are sometimes called.

Among the proofs that this chink, or glottis, is the seat of voice, it may be mentioned, that if an aperture exist in the windpipe, the sound of the voice ceases. Such an aperture is frequently formed in man as a surgical operation, and an opening has often been made in the same situation in animals for the purpose of experiment. Also, when an opening exists above the glottis, that the voice is not lost. Again, that though the epiglottis, the superior vocal ligaments of the larynx, and the upper part of the arytenoid cartilages, be injured, the voice is not lost: moreover, that in living animals, when the glottis is laid bare, it is seen that the inferior ligaments of the larynx which form the boundaries of the fissure termed glottis, are

thrown into vibration: it is known, too, that the division of the laryngeal nerves supplying the muscles, which regulate the states of the aperture, and make the vocal cords tense, destroys the power of producing vocal sounds. It is also found that sounds can be produced in the dead human body by forcing a current of air from the windpipe through the larynx, provided the vocal cords be in some degree tense and the glottis be narrow. The larynx has been cut from the body, and freed from all the parts in front of the glottis; thus, the epiglottis, the upper vocal ligaments, and the ventricles of the larynx between the superior and inferior, or vocal ligaments, the greater part of the arytenoid cartilages, namely, their upper part, may be removed — in short, if nothing remain but the inferior ligaments or vocal cords, and these be so approximated that the glottis shall be narrow, clear tones will be produced by forcing air through it from the windpipe.

Such facts as these entitle us to regard the glottis and the vocal cords, which form its immediate boundaries, as the essential source of voice, while the windpipe simply conveys air, and the cavities above the glottis, comprehending the upper part of the larynx and the air passages through the mouth and nostrils, correspond to the tube of a musical instrument, by which the sound is modified, but not generated.

It has been already remarked that the vocal ligaments are composed of elastic tissue, and that it is owing to this elasticity that they are adapted to the office which they perform. While, then, it is quite certain that no proper vocal sounds can be produced, except in the glottis, it seems manifest that the adjacent somewhat abundant tissue of the same kind is susceptible of a vibration and resonance in unison, so as at least to modify the sounds of the voice.

In reference to the second question — what is the nature of the change produced in the glottis during the formation of voice — no inconsiderable difficulty is met with. The points of debate which have arisen on this subject are, whether the vocal ligaments be a set of membranous cords obeying the laws of musical strings; if the aperture of the glottis be a reeded instrument, in which the vocal ligaments play the part of vibrating tongues; or even whether the real source of the sounds of the voice be not a molecular vibration of the air, produced by its passage through the narrow aperture of the glottis; and, lastly, whether the organ of the voice does not in part combine all these three sources of sound, so as to be at once, in some respects, a stringed instrument, a tongued instrument, and a simple wind instrument.

The ancients regarded the sounds of the voice as analogous to those of a flute. According to this view, the vibrations of the larynx are of little account, the actual sounds being produced by a

molecular undulation of the air. That the organ of voice is not, in some degree, analogous to this kind of musical instrument, is not to be absolutely denied, but it is certain that this is not the principal mode in which the sounds are produced.

One of the earliest ideas of modern times on the subject of the voice is, that the larynx is analogous to a horn; that is to say, to a wind instrument, in which the vocal cords act the same part as the lips of the performer on a horn. Not much more than a hundred years ago arose the idea that the larynx is a set of musical cords — namely, that the vibrations of these cords, on the same principle as a stringed instrument, produce the sound, which is then conveyed outwards by the air.

The prevailing opinion of the present day is, that the larynx is a wind instrument, but a reeded wind instrument.

This common view may be expressed as follows:—the expired air is thrown into the larynx through the windpipe by the muscular action of the chest; the proper muscles of the larynx being contracted, create a sufficient tension of the vocal cords to permit them to be thrown into vibration by the impulse of the air. The sound so produced is conveyed through the mouth and nasal passages, undergoing various modifications in its passage outwards.

Let us consider then, in the first place, what evidence there is that the organ of the voice is a reeded instrument, with a double membranous tongue.

Fig. 90.

Fig. 91.

In short, the action of the organ of voice may be best explained in general terms, by comparing it with the pipe of an organ. Let us suppose Fig. 90 to be the wind-tube, into which the air is driven from below; *b*, the stopper, in which is placed the tongue; *a* and *t′* the body-tube; and let there be a pipe, *o* (Fig. 91), to the wind-box, *c c*, and the air be driven from the bellows, *f f p*, through *t*. The air throws the tongue, *a* (Fig. 90), into a state of vibration, and passes out in undulating movements from the body-tube. Such is a general view of the nature of voice.

An experiment has been before referred to, which illustrates the

effect of an elastic organic tissue, like that of the vocal ligaments, in producing sound on the principle of a double tongue. The extremity of a tube is closed by two bands of moist elastic tissue, for example, arterial tissue, so applied as to cover the whole end of the tube, with the exception of a slight fissure between the bands. In the experiments before referred to, India-rubber, or leather, was mentioned as being employed for this purpose. Both these substances produce a similar effect, but it appears that the middle arterial coat, being composed of the same tissue as the vocal ligaments, and having the same physical properties, forms the best kind of artificial larynx. When this tube is blown through at the free extremity, the tongues not only vibrate readily, but produce a range of musical tones. To obtain a pure quality of tone, it is necessary that the two membranous bands should be of equal weight and breadth, and subject to equal tension, otherwise they cannot vibrate equally in equal parts of time.

If the human larynx be dissected out, and the vocal cords be stretched, they will vibrate like a piece of artificial tissue, such as India-rubber or leather, in a current of air. In conducting these experiments, the same conditions must be secured as are required in the experiment with the tube, and the two membranous laminæ, before referred to. For example, the inner edges of the glottis, that is to say, of the vocal ligaments, must be turned outwards towards each other, so that they shall be in the same plane and parallel to each other, otherwise they will not produce any sound. Hence it may be inferred, that when the tension of the vocal ligaments takes place in the living animal, they turn upon their axis, till their planes which, in the state of relaxation, are inclined to the axis of the vocal tube, become perpendicular to it, and as the edges of the glottis approximate, its chink is nearly or entirely closed, and they acquire the true vibrating position. The production of the most simple tones of the voice requires the associated action of a most extensive range of organs; for it is calculated that in the ordinary modulation of the voice, more than one hundred muscles are brought into action at the same time.

As the air rushes up from the windpipe, a portion of each edge of the glottis yields to its pressure, and is curved upwards, so as to form an angle with the axis of the vocal tube, and leave between the two edges a narrow aperture, through which the air escapes. The tension and elasticity of the vocal ligaments tend to restore them to the plane of their former position. The air having been rarefied below the glottis during their elevation, becomes dense from their depression, and the necessary force being again accumulated, they are re-elevated, and thus an oscillating movement, consisting of an opening and closing of the glottis, takes place, which being com-

municated to the contiguous air, the sounds of the voice are produced.

The vibrating edge of the glottis varies in length according to the pressure of the column of air in the windpipe, and the resistance of the vocal ligaments. When other circumstances are alike, the intensity of the voice is determined by the pressure of the column of air in the windpipe, and the range of movement described by the vibrating edges of the glottis. The pitch of the voice does not depend solely on the tension of the vocal ligaments, but jointly on the variations which they undergo in length and tension. Magendie observed, in the larynx of a dog, that a longer portion of the vocal ligaments vibrated while grave tones were produced, and that a diminution of length accompanied the succession of acute tones. Mayo has described the movements of the glottis in a man who had attempted to destroy himself by cutting his throat. The larynx in this case was cut through just above the vocal cords, and, owing to the oblique direction of the wound, an injury of the arytenoid cartilage and of the vocal cord on one side had occurred. When respiration was going on, the glottis was seen to be of a triangular form, but when the voice was exerted, the vocal cords passed into a parallel direction, and the glottis itself had a linear form. The posterior part of the aperture appeared to remain unclosed.

Fig. 92.

The cut represents the prepared head of a corpse, after Müller. A thread *e*, which passes over a roller to a scale, is so applied to the larynx that the tension of the vocal cords can be increased by placing a greater weight on the scale. The action of the muscles is thereby imitated. The compressing apparatus seen on the wood-cut brings the vocal cords nearer to each other, and thus produces the requisite diminution in the width of the vocal fissure. The tube *f* serves to convey the wind, which throws the tongue-apparatus into action. And thus, if we use the human head, or the head of the dog, or of the pig, or of any other animal, we can imitate the voice of man, the bark of the dog, the grunt of the pig, &c.

Membranous tongues, like those in the larynx, differ widely from a metal tongue, shutting up the aperture, and necessarily opening and closing as the air issues.

Objections have been taken to the view which represents the voice as the result of sounds produced by membranous tongues set in motion by air, 1st, That the vibration of tongues consists in the periodical opening and shutting of the orifice through which the stream of air passes, this not being the case in the glottis; 2nd, That had it the structure of a reed, the edges of the vocal ligaments which open the chink would be alternately separated by the column of air in the larynx, and drawn together by their tension, while it has been found by experiment that air transmitted through the glottis gives rise to sound, notwithstanding that its edges are from one-sixth to one-fourth of an inch asunder. In these objections, however, there is a mistake as to the essential principle of reeds—for those of the clarionet, bassoon, hautboy, &c., fail to close entirely the passages through which the breath escapes; and the case is not otherwise with the natural reed, which the lips of players on the flute and horn represent. In short, a sound can be produced by a tongue apart from the surrounding framework, indicating, beyond doubt, that so much importance should not be ascribed to the usual mode of forming reeded and tongued instruments, and to the circumstance of the air passing between the tongue and its frame. It has been shown that the law by which the variation in the notes yielded by the tongue of a mouthpiece or reed is regulated, is the same when the tongue is made to vibrate by a current of air, as when it is thrown into vibrations by being struck or inflected. By the same law are regulated the vibrations of vibrating rods; the frequency of the vibrations of two rods of the same texture and thickness being in the inverse ratio of the squares of their length. The note afforded by a reed without a tube is of the same pitch, whether it be the result of a current of air, or be produced by striking the tongue. The strength of the blast does not, for the most part, determine the pitch or sharpness of the note; but when the force of the blowing is increased, the strength of the tones is augmented. The size of the fissure between the tongue and the frame within which it vibrates, is of little consequence; when the opening is large there is a greater difficulty in obtaining the tone, but its pitch is not altered.

Some slight difficulties may still exist in the explanation of the theory of the voice as considered to be chiefly the result of a double vibrating tongue; but, altogether, as close a resemblance has been proved to exist between that kind of artificial musical arrangement and the structure of the living larynx, as can reasonably be expected in such a case.

It was already hinted that the vocal ligaments may possibly act not only as vibrating tongues in the production of voice, but also on the principle of musical strings. On this point a few words must be added. It may seem at first sight that the remark of so distinguished a philosopher as Biot, when he says, "What is there in the larynx that resembles a vibrating string? Where is the space for such a string of sufficient length to yield the lower notes of the voice? How could sounds, of the compass which the human voice represents, be produced by a string which the larynx would contain?" would suffice altogether to set aside the idea of the vocal cords acting as musical strings. But Biot here seems to have fallen into error. Deep notes are still produced by a string greatly shortened, if it retain, after a sufficient amount of relaxation, the elasticity required for vibration. His attention does not seem to have been drawn sufficiently to the nature of organic membranes, strips of India rubber and elastic animal membranes still retaining enough of elasticity for this purpose, after being much relaxed. There is, therefore, a perfect agreement between the vocal cords and vibrating strings, though their vibrations, whether as strings or as tongues, are produced not by the direct impulse of a solid body, but by the momentum of air. When the ordinary principles to which musical strings are subject are applied to the vocal ligaments, there is found to be a very close agreement, if allowance is made for the peculiarities of elastic animal substances as respects elasticity and the like.

In their ordinary state, the vocal cords must be regarded as subject to a considerable tension, which, however, admits of being diminished, so as to add to the range of the lower notes. At the ordinary pitch of the voice, the glottis may be regarded as partially closed, and becoming more open as graver tones are produced; this opening of the glottis coinciding with the relaxation of the vocal cords, a double cause is afforded of the lowering of tone. When higher notes are uttered the glottis closes, assuming more of a linear form, while, at the same time, the vocal ligaments, though elongated, are thrown into a much higher state of tension. In the words, then, of Mr. Bishop, "since the vocal ligaments have been proved to extend and contract for acute and grave sounds respectively, and after death vibrate in a great measure like musical strings, we think it may be fairly inferred that they likewise obey, to a certain extent, during life, the laws of the vibrations of such strings." * * * * "It is moreover observable, that the extension and relaxation of the vocal cord, which, as we have seen, are analogous to those of a musical string, produce a corresponding shortening and elongation of its axis, regarded as a tongue; and, lastly, since one tone only is produced at a time, the vibrations resulting from the double action which appears to exist in the vocal apparatus must be synchronous."

* * * * "It might possibly be objected to the idea of this two-fold action, that the production of sound by the vocal cords is sufficiently accounted for by supposing them to vibrate merely as elastic tongues; but then it is found by experiment, that by artificially dividing their length into two ventral segments, there results the octave of the fundamental note, which proves that at all events they vibrate as cords. In conclusion, we must bear in mind the vast difference between natural and artificial mechanism, and however complicated a problem it may be to determine that constitution of the vocal apparatus, by which the thyro-arytenoid ligaments may simultaneously obey the laws of cords and tongues, yet to a physiologist who is accustomed to meet with the most admirable contrivances and combinations in the animal frame, the difficulty of finding a strictly mathematical solution is, in such a case, no objection to its truth, when the facts, as far as they have been observed, are decidedly favourable to its reality." — *Cyclopædia of Physiology, article Voice*, p. 1481.

It was before hinted at, that the vibrations of the walls of the tubes through which the voice is conducted may, in some degree, influence its sound. In rigid tubes, the vibrations depend on the nature of the impulse propagated in the air within, jointly with the length of the pipe. So long, then, as the length of the pipe remains the same, and no change takes place on the material of its walls, the pitch of the sound produced by the undulations of the air within, remains unaffected. The dimensions of the windpipe, such as its length and diameter, are invariable; and, were the height of the larynx, and the dimensions of the bifid tube (the nose and mouth) through which the air issues after the formation of voice, equally invariable, the vibrations of these parts would produce no change on the pitch of the voice, the quantities being constant for each tone produced in the glottis. It has been found that, by taking tubes composed of layers of paper, of constant length, but varied in thickness, graver sounds were produced as the parieties became thinner, and that the gravity of the sound was increased by moistening and relaxing the sides of the tubes. It was before noticed, that the windpipe is capable of being drawn upwards from the chest to a small extent, while the larynx is elevated, and that this tube admits of being diminished in its diameter by about one-third part. Moreover, the pharynx, the mouth, and the nasal cavities are also susceptible of various modifications of diameter, so that the pipe, so to speak, near the middle of which the vocal sound is produced, is in a very different condition from a rigid tube. Hence, it has been concluded that provision is made for an invariable adaptation between the amount of tension, the vibrating length of the vocal ligaments, and the walls of the vocal tube, for the production of the ordinary

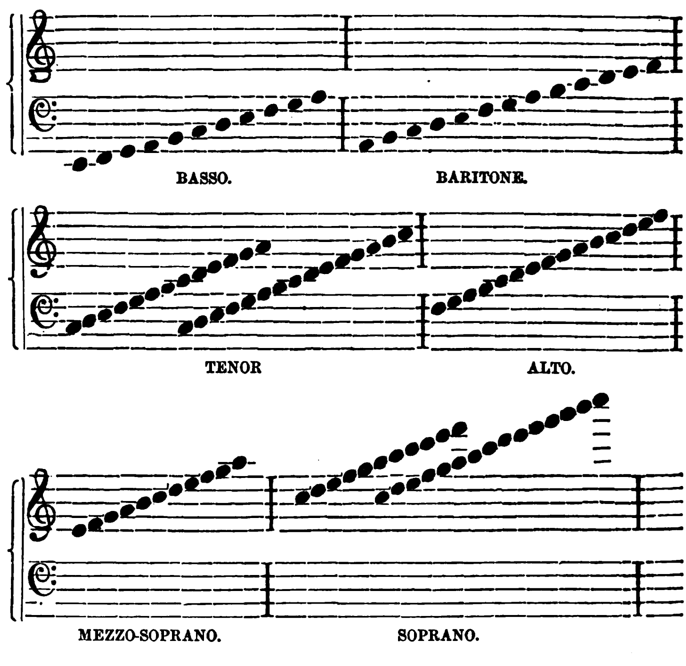
tones of the voice. It appears, indeed, to have been proved that the vocal tube is so short, that were it rigid, it could not influence the pitch of the note which the glottis originates. But its want of length is compensated for by the relaxation of its walls, so that it comes to vibrate synchronously, and so to give forth sounds equally grave with those of the glottis. Its effect, therefore, is to add to the force of the tone, which, without its aid, would have been found to possess less intensity.

After considering this subject in every possible light, the conclusion appears to be that to which Mr. Bishop has come, namely, that the evidence shows "the vocal apparatus to be influenced by the air expelled from the chest, in precisely the same way as if it were a stretched cord, a reed, or a vibrating tube. Why, then," he continues, "should we hesitate to adopt the obvious conclusion that the vocal organs do, in fact, combine the properties of these various instruments, and are thus the perfect types of which these instruments are only imperfect imitations?"

Singing.—The notes of the human voice are capable of being produced in three separate kinds of sequence. In ordinary speaking, the successive notes have nearly all the same pitch. This kind of succession, then, is properly termed the monotonous. Some deviation from this monotony occasionally arises, as when certain syllables receive a higher intonation for the sake of accent, and when, in reading or reciting poetry, rhythm is added to the accent. In these cases, however, the deviation from monotony of pitch is too slight to require a separate head. In the expression of passion, accompanied by vehement exercise of the voice, there is heard a sudden transition from high to low notes, or the reverse. This, then, constitutes the second kind of sequence in the notes of the human voice. Musical notes constitute the third mode of sequence. In music the sound has the requisite number of vibrations, and as the sounds succeed each other they exhibit that relative proportion in the number of vibrations which jointly characterize the notes of the musical scale. Of the adaptation of one sound to succeed another, so as to preserve the musical character of the succession, the human ear is the only original standard.

Compass of the Voice.—In singers the compass of the voice extends through two or three octaves. When the male and female voices are taken together, the entire scale of the human voice includes four octaves. The lowest note of the female voice is about an octave higher than the lowest of the male voice; the highest of the female voice is about an octave higher than the highest of the male. The first four notes of all voices are most commonly weak. There are two kinds of male voice, the bass and tenor; and two kinds of female voice, the contralto, and soprano. The essential

distinction between these voices does not consist in their difference of pitch. The bass voice commonly reaches lower than the tenor, and its strength lies in the low notes; while the tenor voice extends higher than the bass. The contralto voice has most commonly lower notes than the soprano, and is strongest in the lower notes of the female voice; while the soprano voice reaches higher in the scale. It is found, however, that bass singers can sometimes go very high, and the contralto not unfrequently sings the high notes like soprano singers. The difference between the bass and tenor voice, and between the contralto and soprano, is plainly, then, not one of pitch, but consists in the peculiar timbre or quality of the notes—for these several voices are distinguished from each other even when sounding the same note. The qualities of the baritone and mezzo-soprano voices are less marked; the baritone being intermediate between the bass and tenor, the mezzo-soprano between the alto and soprano.



The difference of pitch between the male and female voice is connected with the different length of the vocal ligaments in the two

sexes. It appears that the lengths of the male and female vocal cords in repose are nearly as 7 to 5, and in tension as 3 to 2; in boys at the age of fourteen the length is to that of females, after puberty, as 6·25 to 7, — so that the pitch of the voice is nearly the same. The difference in the quality of the female voice, as compared with that of the male, is owing to the considerable difference presented by the two sexes in the walls of the larynx; the male larynx being much more expanded, and forming a much more acute angle in front. It is not yet clearly understood what is the cause of the different qualities of voice, as exhibited in the tenor and bass, and the contralto and soprano. As Müller remarks: "We may form an idea of the cause of these differences of timbre, from recollecting that musical instruments made of different materials, as metallic and gut-strings, metallic, wooden, and membranous tongues, metallic, wooden, and paper pipes, or flutes, may be tuned to the same note, but that each will give it with a peculiar quality or timbre."

In short, when the variations of the larynx in different individuals of both sexes, and at different ages, under the various circumstances more or less favourable to the development of the respiratory organs, are considered, as well as the remarkable fact that every human being is characterized by a speaking voice peculiar to himself, we shall be at no loss to understand why the singing voice should vary in different persons, not only in pitch, but also in quality.

The voice termed falsetto has much engaged the attention of physiologists. Most singers, particularly males, besides their natural voice falling under one or other of the before-mentioned characters, have the power of producing a double series of notes, of a different description. To the second series of notes the name of falsetto is applied. The notes of the natural voice — called also chest-notes — are fuller, and distinctly indicate a stronger vibration and resonance, while the falsetto voice has more of a humming character. It is only with the natural voice that the deep notes can be produced, while the highest notes of a male voice are falsetto. The notes belonging to a middle pitch may belong either to the natural or the falsetto voice. Thus the two registers, as they are termed, of the voice are not bounded in such a manner that the one ends where the other begins, as, through a certain compass, they run side by side. It is remarked that the bass voice becomes falsetto lower in the scale than the tenor. In the female voice there is less seldom presented very marked distinction between the natural and falsetto registers.

In a human larynx detached from the body two distinct series of tones can be produced, when the tention of the vocal cords is very slight. One of these series corresponds to the tones of the ordi-

nary voice, the other to the tones of the falsetto voice. With a certain degree of tension of the vocal cords both these kinds of tones may be produced; sometimes the one kind, sometimes the other, being heard. With a different kind of tension of the cords, notes of the falsetto character are constantly produced, whether the current of air passing through the glottis be forcible or feeble. If the vocal ligaments be much relaxed, the sounds of the ordinary voice always result, whether the current be feeble or forcible. When a slight tension of the ligaments is kept up, the falsetto is most easily produced by blowing very gently; while if the blowing be more energetic, the sound belongs to the ordinary voice. Thus, two different notes may be produced, under the same degree of tension of the ligaments, by a different force in the blowing; and the distance of these two notes from each other may be as much as an octave. "The real cause," says Müller, "of the difference between the falsetto and the notes of the natural voice is, that for the former the thin aperture only of the lips of the glottis vibrates, while for the latter the whole breadth of the cords are thrown into strong vibrations, which traverse a larger sphere." The peculiarities of the voice in different individuals must be chiefly dependent on the particular form of their air-passages and of the lining membranes, and the consequent differences in their mode of resonance. That such causes are adequate to produce all the varieties of the voice in individuals, appears from the circumstance that many persons, by altering the form of their vocal organs, can imitate the various tones of the voices of other individuals.

The usual quality of the voice is determined by like causes. This nasal tone appears to be given to the voice in two ways; thus a nasal sound is produced, though the external openings of the nostrils be closed when the arches of the palate approach each other, and the larynx ascends higher than in the natural voice. When the nostrils are obstructed by mucus a nasal sound is produced; this obstruction having the same effect as the voluntary closure of the anterior opening of the nostrils. In the second mode by which the nasal sound is produced, the nostrils are open, the larynx ascends considerably, the arches of the palate contract, the upper surface of the tongue ascends towards the palate, so that the air passes between the narrowed arches of the palate, and receives the resonance of the nasal cavities without that of the cavity of the mouth. The deficiency of tone in the voice of old people arises from the ossification of the cartilages of the larynx, and the altered state of the vocal cords. It is unsteady, owing to the loss of nervous command over the muscles.

The strength of the voice depends partly on the extent to which the vocal cords are capable of vibration, and partly on the great capa-

city of the chest, and the fitness of the various parts over which the air passes for communicating resonance. The intensity or loudness of a given note cannot be rendered greater by the mere augmentation of the force of the current through the glottis. Such an increase of force in the current will raise the pitch both of the natural and falsetto notes. It is therefore concluded that the variation in the intensity of a note, without the alteration of its pitch, must depend on some other cause than the mere change in the force of the current. Such a provision plainly lies in the power of modifying the tension of the vocal cords. To render a note more intense, without increasing its pitch, the vocal cords must be relaxed in proportion as the force of the current of the breath through the glottis has increased. When it is desired to render a note fainter, an opposite mode of action must be adopted.

The failure of perfectness in the notes of the human voice may arise from many causes. Variations in the temperature of the atmosphere, and in its states of humidity, have a powerful influence on the pitch of the voice. While a cold, moist state of the atmosphere prevails in England, the voices of singers become lower by two or three notes, while they regain their usual pitch when the air becomes dry. Mr. Bishop mentions that when Grassini came to England, owing to the change of the air from that of Italy, her voice became one octave lower. After singing for two or three seasons her natural voice returned, but it had lost its attractions with the loss of the low tones which had gained her so great applause. After long singing dissonance of the voice is apt to arise; this is easily accounted for by the slight changes produced on the vocal cords in consequence of repeated tension, together with the fatigue of the muscles concerned, which, as in other cases of muscular contraction, at length cease accurately to obey the will, and hence arise unsteady movements.

Whistling.—Before leaving the subject of the human voice, whistling deserves a few words. The sound in whistling does not arise from the vibrations of the lips. Several experiments prove that the lips are not thrown into vibrations. They may be touched, covered, or may have a disc of cork with a central hole placed between them, and yet the same sounds will be produced. It has been supposed, then, that the air is thrown into sonorous vibration by friction against the borders of the opening. According to Müller, the cause of the vibration is the same friction of the air; but the vibration produced upon the borders of the opening throws the whole column of air in the mouth into vibrations, and these by a reciprocal influence, determine the rapidity of the vibrations of the air at the orifice. The only difference, according to him, between whistling and the sounds of a pipe is, that in whistling the whole

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column of air is in constant progressive motion through the tube and orifice, while in a pipe the air in the tube merely vibrates, and does not move as a current.

Speech.—Speech is peculiar to man. Because speech is not possessed by individuals deprived of the organs of voice or of hearing, it is not, therefore, to be concluded that it originates in the mere possession of these organs. Inferior animals are fully provided with the organs both of hearing and of voice, and yet, in all essential respects, they are destitute of speech. Speech, therefore, must be considered under the light of a potentiality of man's intelligence, the condition of the exercise of which is the presence of the organs of hearing and of voice. That is to say, man is born susceptible, by the development of his nervous system, of the acquisition of speech, provided his organs of hearing and voice are perfect. But if man be born susceptible of speech, it may be asked, why does not the deaf-mute invent a language? He does invent a language, but it is a language of expression independently of speech; he fails to express his inward feelings by the use of speech, because the defect of hearing prevents him from discovering the sounds which his voice is capable of producing. His language, therefore, is confined to the other modes of expression by which an intercommunication, however, imperfect, can be carried on between men. The deaf-mute might undoubtedly carry the use of the natural signs of expression much farther, were he not overwhelmed and overpowered by the multitude of ideas which his fellow-men around him possess, and are continually striving to make him understand. It may also be asked if, owing to this natural susceptibility of speech, every infant should not invent a language. In so far every infant does invent a language, but as, long before any progress is made in its language, the sounds which it continually hears are caught up, it is impossible to judge to what extent each individual is capable of carrying such an invention.

There is no more interesting speculation than to consider the several steps by which language must have arisen among men. It is easy to understand how, in the rudest community of mankind, conventional signs must have arisen of every description; nor is it difficult to perceive that those sounds of speech which are most easily produced would quickly form a large share of those conventional signs. But it forms no part of our present design to investigate the origin of languages; it is more to the purpose to consider, in a few words, how men came to understand the several acts concerned in speech. At a certain period, then, in the progress of mankind, it appears that languages of no inconsiderable extent had already been formed, and yet that no attention could have been paid to the individual sounds composing those languages. Men spoke, and in that

speech employed words without the least reference to letters, and perhaps with none even to syllables. The curious inquiry, then, which arises is, in the first place, how men were led to reduce speech to letters; that is, to analyse words into their elementary sounds.

We may suppose that the difficulty of pronouncing certain sounds, such as the words of a foreign language, must have been the first circumstance which would lead men to reflect on the modes by which speech is produced. Man's natural curiosity would not fail to engage him more largely in this inquiry as soon as the subject was suggested. Little progress, however, could be made in this pursuit till some method of fixing the sounds by name, and of representing them to one's self, or to others, at periods more or less distant from their first recognition, was invented. It may be supposed that men had already acquired the art of depicting objects of sight, were it no more than rude representations made with a rod on the sands left by a receding sea. The idea, however, of representing a sound by such a symbol is plainly not of the same kind. To think of representing a sound by a symbol is manifestly a fresh step in discovery. It required, in short, an effort of invention to produce such a stretch of thought. But the moment the idea arose all difficulty must have vanished. Nothing was easier than to observe the similar simple sounds occurring in the compound sounds which constitute speech. The mere observation of the form of the mouth, as certain simple sounds are uttered, would be sufficient to afford a foundation for this kind of knowledge. What the original symbols corresponding to our modern alphabets were, is of little moment. The first alphabets, doubtless, consisted of the representatives of but a small number of sounds. It is easy, however, to perceive that as soon as this kind of investigation was fairly commenced, it would make rapid progress, there being no great difficulty in discovering the collocation of the several parts of the mouth concerned in the production of most of the simple-sounds. Thus, by an easy analysis, syllable-sounds would be reduced to letter-sounds, and each letter would quickly come to be marked by a particular symbol. The most remarkable effect of this great discovery, simple as it seems to us, would unquestionably be the rapid multiplication of sound-symbols —that is to say, the vast extension of language. The greatness of the discovery hardly strikes us at the first sight. Some idea of the character of it is obtained from the fable of words spoken becoming frozen at the moment in their fixed forms, and not reaching the ear until the return of a more genial temperature. Letters, in short, are the pictures of sounds, by which any sound now pronounced is perpetuated, while the picture itself, or a copy of it, shall endure.

Speech, then, consists of combinations of sounds produced in the larynx, and variously modified in their transition through the oral

or nasal passages outwards. No language exhausts all the sounds which can be produced in the passage of the voice outwards in this manner. Languages may be described as composed of those sounds which are most easily produced in the passage of the voice from the larynx outwards into the atmosphere. And languages differ from each other chiefly by presenting various predominant groups of such sounds. The chief distinction of the sounds of speech is according as they are transmitted through the oral canal before spoken of, or the nasal passage. Another important distinction between articulate sounds is, that some are only of momentary duration, taking place during a sudden change in the conformation of the mouth, and are not capable of prolongation by a continued effusion of the breath, while others can be prolonged all the while that a particular disposition of the mouth and a constant expiration are maintained.

The same sound produced in the larynx is converted into any one of the vowel-sounds merely by a modification of the parts of the mouth through which it passes. The parts of the mouth concerned have been termed the oral canal and the oral opening. The oral canal, it is to be remembered, is the space between the tongue and the palate; the oral opening is the aperture formed by the lips. Some physiologists have described five degrees of size in each of these two parts — that is, five degrees of size in the oral canal, and five degrees of size in the oral opening. One sound, then, produced in the larynx is converted into *a*, *e*, *i*, *o*, *u*, according to the modifications in the size of these two parts. Thus when the size of the oral canal is in the third degree, and the size of the oral opening is in the fifth or highest degree, the act of voice is converted into the sound of the English *a* in *far*. When the size of the oral canal is in the second degree, and that of the oral opening in the fourth degree, the sound of the English *a* in *name* is produced. When the size of the oral canal is in the first or lowest degree, and that of the oral opening in the third degree, the sound of the English *e* in *theme* is produced. When the size of the oral canal is in the fourth degree, and that of the oral opening in the second degree, the sound of the English *o* is produced. When the size of the oral canal is in the fifth or highest degree, and that of the oral opening in the first or lowest degree, the sound of *u* like *oo* in *cool* is produced. Of the general truth of this statement any person may satisfy himself by remarking, when he utters the broad *a*, how much he opens his mouth, simply breathing forth the voice with open mouth. When, on the contrary, he with the same breath attempts to pronounce *e*, he finds the mouth close considerably, and the tongue rise towards the roof of the mouth, so as to contract the oral canal. In pronouncing *o* he will observe how the lips are thrown into the form of the letter, the tongue at the same time raised from the bottom

of the mouth. The form of the vowel *o* in most languages points to one source of origin of those representations of sounds which we call alphabets.

Some consonants, like vowels, can be pronounced with an uninterrupted sound, which continues as long as the expiration can be prolonged, the disposition of the parts within the mouth remaining throughout as at the commencement of the sound. Of these, the aspirate *h* is pronounced with the whole oral canal open; no interruption is offered to the passage of the breath; its sound is the simple result of the resonance of the walls of the cavity during expiration. Others of the same class, such as *m*, *n*, and *ng*, are produced by continuous expiration through the nasal canal, the aperture of the mouth being closed either by the lips, or by the tongue being pressed against the palate. The mouth is closed by the lips while *m* is pronounced, the sound being produced by the simple passage of the air through the nasal cavity. When *n* is pronounced, the mouth is closed by the extremity of the tongue being pressed against the fore part of the palate. *Ng* is regarded as a simple sound in the words *sing* and *bang*. It is produced also by the passage of sound through the nostril, while the posterior part of the tongue is pressed against the palate. Other consonants, again, of the same class, are continuous sounds developed by the valve-like application of different parts of the mouth to each other, such as *f*, *s*, *r*, *l*. *F* is pronounced by the application of the lower lip to the teeth. In pronouncing *s*, the teeth are brought into contact with each other, while the point of the tongue touches the lower teeth; in the sound of *r*, the tongue vibrates against the palate; in the sound of *l*, the point of the tongue is applied close to the palate, and the air escapes between the tongue and the cheeks. The English *th* is a modification of *s*.

The mute consonants with explosive sounds are next to be spoken of. The organs of speech by which these sounds are formed undergo a sudden change of position during their production. The sound commences with the closing of the mouth and terminates when it opens—that is to say, these consonants cannot be prolonged at pleasure; *b*, *g*, *d*, of which *p*, *k*, *t* are modifications, coming under this head. In sounding *b*, the lips are brought together and close the mouth, while they separate again at the moment the air is expired. In sounding *d*, the tongue is applied to the anterior part of the palate, or to the upper teeth, so as to close the mouth, which opens with the escape of the breath. In sounding *g* — that is, the hard *g*, as in *gold* — the momentary closure of the passage through the mouth takes place, more posteriorly, by the application of the back part of the tongue to the palate. In sounding *p*, *t*, and *k*, the requisite modifications of *b*, *d*, and *g* are produced by a stronger as-

piration during the opening of the mouth, which was previously closed. All the sounds hitherto mentioned are capable of being pronounced in a whispered speech. The English *y* and *z* cannot be uttered without an accompanying vocal sound. Thus, when an attempt is made to sound the English *y* in a whisper, the German *ch* is produced in its stead. All the vowels are capable of being produced equally in whispered speech, and with a vocal tone. Many consonants also, as *f*, *s*, *r*, *l*, *m*, *n*, *ng*, can be pronounced either with mute sounds or with vocal intonations. The continuous consonant *h* can only be pronounced in whispered voice; and it is quite impossible to combine the sounds of the explosive consonants, *b*, *d*, *g*, and their modifications, *p*, *t*, *k*, with an intonation of the voice.

Besides the ordinary sounds of consonants which enter into the formation of languages, other sounds are capable of being produced in the mouth and throat. The smacking sounds produced by the separation of the teeth from the tongue or palate, are reported by travellers to occur in the language of the Hottentots and in those of other African tribes.

The several sounds and tones of language can even be imitated by artificial contrivances. When the sound of the voice is made to pass into a cylindrical tube, before which the hand is held, and then withdrawn, the sound of *b* is produced; and if the tube be a pipe with a membranous tongue, the sound of *v* is produced. Various speaking machines, by attention to such principles, have been constructed; the most perfect of these is that contrived by Faber. The automaton invented by him has a singing voice extending over twelve notes. The difference in the height of the notes is made by varying the width of the glottis without tension of the cords. In this respect it is hardly an exact model of the human organal voice.

The singular faculty possessed by ventriloquists has engaged much of the attention of physiologists. Many different views as to the nature of this kind of speech have been at various times brought forward.

One of the oldest and most common ideas on this subject is, that ventriloquism consists in speech produced during inspiration. It is unquestionably possible, though not without difficulty, to articulate during inspiration, and the sounds so produced have some resemblance to the tones uttered by a ventriloquist.

A more recent view of the nature of ventriloquism is, that it is a mere imitation, produced in the larynx, of the various modifications which the voice ordinarily suffers from distance, by the interposition of a partition, as if the individual were enclosed in a narrow space, — in a trunk, a cask, or the like. This view has been supported with much ingenuity by Magendie.

The distinguished German physiologist, Müller, has adopted an

idea on this subject which coincides better with the original name of this artifice. He says that the notes of ventriloquism are produced by inspiring very deeply, so as to protrude the abdominal contents by the deep descent of the diaphragm, and the diaphragm being retained in this position, by speaking through a very narrow glottis, expiration is performed very slowly by the lateral walls of the chest alone. He affirms that the quality which the voice has in speaking through an expiration thus performed, is that peculiar to ventriloquism, and that sounds may be thus uttered which resemble the voice of a person calling from a distance.

A very large share of the artifice practised by the ventriloquist, particularly in the imitation of voices coming from particular directions, lies in the deception of other senses besides the hearing. The directions in which sounds reach the ear are never very easily distinguished; and when the attention is drawn to a different point, the imagination is very apt to regard the sounds produced as coming from that quarter.

Of the imperfections of speech, stammering is that which has been chiefly investigated; and it lies in a momentary inability to pronounce a consonant or vowel, or to connect it with the preceding sounds. This impediment may occur either in the commencement or in the middle of a word. When the impediment arises in the middle of a word, the commencement of the word is often several times repeated. Hence stammering is apt to be defined as the successive repetition of one sound. The repetition of the commencement of the word, however, is not the essential defect which constitutes stammering; it merely marks repeated attempts to overcome the difficulty. Neither is it correct to say that the difficulty in stammering lies chiefly in pronouncing the consonants, for the impediment most frequently occurs in the case of vowels. The best account which has been given of the nature of stammering is, that it depends on the momentary closure of the glottis, so that the passage of the air necessary to the pronunciation of the particular sound is arrested. In persons severely affected with this impediment, there are manifest indications of the struggle at the glottis, occasioned by the impediment to expiration, in congestion of blood in the head and in the veins of the neck. The real cause of stammering, therefore, must be described as an unusual movement in the larynx, associated with the articulate movements. In short, stammering is a temporary spasmodic affection of the glottis. For the prevention of stammering, the proper plan is to endeavour to bring the associated movements of the larynx with the organs of speech more under the command of the will. To sing words is one method of obtaining this effect; since in singing more attention is directed to the action of the larynx than in ordinary speaking. Moreover, it is observed that

persons who stammer pronounce better in singing than in mere speaking. The raising of the point of the tongue towards the palate has some effect in counteracting this habit, and this elevation of the tongue seems to have been the object of the plan practised by the ancients, of placing bodies, such as pebbles, under the tongue. Müller recommends for the cure of stammering that the patient should practice himself in reading sentences in which all the letters which cannot be pronounced without a vowel sound — namely, the explosive consonants, *b*, *d*, *g*, *p*, *t*, and *k*—are omitted, and only those consonants included which are susceptible of an accompanying intonation of the voice. He also directs that all those letters should be very much prolonged. He says that by this means a mode of pronunciation will be attained in which the articulation is constantly combined with vocalization, and the glottis, consequently, never closed.

As already mentioned, dumbness is dependent, not on the defect of the organs of speech, but on the absence of hearing. By assiduous efforts deaf-mutes learn the movements of articulation by means of their sight. The speech which they acquire is most commonly harsh, owing to the want of the sense of hearing to regulate their articulation. There was no discovery hailed with greater interest than that of teaching the dumb to speak; and undoubtedly, harsh though the sounds be—and yet they are not always disagreeably harsh—there can hardly be a greater triumph of human art. It will hardly be believed that some innovators on the education of the deaf and dumb seek to abolish the practice of teaching them to articulate, on the ground that their harsh speech is unfitted for the uses of society, and that they can communicate with their fellows sufficiently by other means, as by speaking on the fingers and by writing. This is a most unwarrantable view of the case of these unhappy persons, particularly when they belong, as by far the major part of them must do, to the labouring classes of society. We have only to consider how many persons one in the condition of a laborour must meet with daily who cannot write, or read writing, to be satisfied that this innovation on the education of the deaf and dumb should be at once put down in every institution in which it has gained a footing. There is every reason to believe, that in proportion as a knowledge of the mode in which the sounds of the human voice in speech are produced becomes better understood, the artificial articulation of the deaf and dumb will become less and less harsh and disagreeable.

Comparative Physiology of Voice.—Organs of voice occur among inferior animals, in the mammalian tribes, birds, and reptiles. In mammals the organs of voice bear a close resemblance to those of man. In birds considerable modifications occur on these organs. In reptiles the apparatus of voice is of greater simplicity.

Voice of Mammals.—Among mammals some are mute, and yet these are not always deficient in those parts of the larynx which are most essential to voice.

Among the orders which compose the class mammalia, the cetaceans, consisting chiefly of the whale tribe, are often described as mute. These animals, however, are not mute altogether, but possess only a single lowing note, or at the utmost they have the power of simply bellowing. There are two distinct sections of cetaceans. The first includes what have been termed the herbivorous cetaceans, such as the sea-cow, *the representative of the popular mermaid*, and the dugong. The second order includes the common cetaceans, popularly known as blowers. The act of blowing, from which they derive their name, consists in the expulsion of water by the nostrils; that is, along with their prey they receive a large quantity of water into the mouth, and while the mouth remains closed they blow out this superfluous water by a hole in the upper part of the head.

FIG. 93.

SECTION OF TONGUE, PHARYNX, AND LARYNX OF PORPOISE—*Museum of College of Surgeons of London.*
a, pyramidal position of larynx; *c*, pharynx; *d*, laryngeal cavities laid open.

This expulsion of water is produced by means of a peculiar arrangement of the veil of the palate. The water accumulates in a sac situated at the external orifice of the cavity of the nose, whence, by the compression of powerful muscles, it is violently expelled through a narrow aperture pierced on the summit of the head. By this contrivance these animals throw forth those jets of water which are seen by mariners at a great distance. The larynx has a pyramidal form, and penetrates into the posterior portion of the nostrils to receive air, and conduct it to the lungs, without the animal being obliged to raise its head and mouth above water for the purpose. As there are no projecting laminæ in the glottis, they can hardly be said to have the proper organs of voice, and thus the noise they make may be described as a simple vehemence of expiration.

The larynx, however, in these animals is highly developed in other respects.

Among the animals commonly described as mute is the giraffe or camelopard, termed by naturalists *Cameleo-pardalis giraffa*. In the giraffe the vocal ligaments appear to be absent.

The armadillo (*Dasypus*) is another of the mammalians described as mute. The only peculiarity of the larynx which has been observed is, that the epiglottis, or valve-like cartilage of the larynx, is bilobed. The armadillo, it will be remembered, is remarkable among mammals for the scaly, hard, bony shell, composed of pavement-like compartments, which cover the head, the body, and even the tail. These animals belong to the order termed Edentata. They live in burrows, which they excavate. To the edentata also belong the ant-eaters (*Myrmecophagæ*), which are regarded as mute. In the same order is found the sloth (*Bradypus tridactylus*). In this animal, however, vocal ligaments are found, and the windpipe is convoluted. The voice is a plaintive melody, consisting of an ascending and descending scale of the hexachord.

Among the Rodentia, or gnawers, the common porcupine of Europe is mute. In this animal it has been ascertained that there are no vocal ligaments.

Such, then, are a few examples of the animals in the class Mammalia, which are mute, or nearly mute.

In the order Ruminants we find animals possessed of a sonorous voice, exemplified particularly in the ox. In the ox the larynx is well developed; there are no superior vocal ligaments, but the inferior or true vocal ligaments are strong, and nearly an inch in length; the windpipe consists of fifty-two cartilaginous rings, that is, nearly three times as many as they number in man. The voice is sonorous, intense — pitched in C = 256 vibrations in a second.

The sheep belongs to the same order of quadrupeds. The larynx differs from that of the ox only in dimensions. The voice is guttural, pitched in F = 341 vibrations in a second.

To the same order belongs the camel (*Camelus Bactrianus*). In the camel the larynx is well developed; the superior vocal ligaments are present, and the inferior vocal ligaments are strong. The voice is grave, but seldom exercised.

In the Pachydermata, or thick-skinned animals, there are many species possessed of a sonorous voice. Among these are the horse, the ass, the hog, the rhinoceros, and the elephant. In the horse the larynx is highly developed, and the windpipe has as many cartilaginous rings as that of the ox. The superior vocal ligaments are not prominent. Above the junction of the proper vocal ligaments, between that and the epiglottis, there is an oval cavity, and on the posterior surface of the epiglottis there is a groove, furnished at its base with a semi-lunar membrane. To this membrane much effect has been ascribed in the production of the peculiar neighing of the

horse. It is doubtful, however, if this peculiar sound be so much dependent on this membrane as has been believed.

FIG. 94.

LARYNX OF CAMEL LAID OPEN — *Bishop*.
a, epiglottis; *b*, superior vocal cords; *c*, inferior; *d*, arytenoid cartilages; *e*, vertical ridge; *h*, tubercle; *f*, trachea.

FIG. 95.

LARYNX OF HORSE—*Bishop*.
a, epiglottis; *b*, semi-lunar membrane; *c*, aperture at base of the epiglottis; *d*, groove; *e*, ventricles; *f*, arytenoids; *g*, inferior vocal cords; *h*, trachea.

In the ass the larynx is also well developed. In the windpipe the rings are spiral. The bray of the ass — which seems greatly to depend upon the presence of two large sacs placed between the vocal ligaments and the internal surface of the thyroid—is well known; it has a range of about five tones.

In the mule the larynx resembles that of the ass. The voice is a species of bray, more resembling that of the ass than the neighing of the horse. The tapir (*Tapir Americanus*) has some peculiarities in its larynx. It has, however, superior vocal ligaments, which are short and distinct, and inferior vocal ligaments, which are strong. The voice is a species of whistle.

The hog (*Sus scrofa*) has also some peculiarities in its larynx; its voice, as is well known, is a grunting, discordant sound.

The rhinoceros is remarkable for having the superior vocal cords very prominent.

In elephants the larynx is largely developed. The superior vocal ligaments are indistinct; the inferior or proper vocal ligaments are strong. The windpipe exhibits thirty rings, which are often partially subdivided, as in the case of the bronchial ramifications. The voice, aided by the trunk, is intense, and of a grave pitch.

Under the head of Marsupial animals, we find the kangaroo and the opossum.

FIG. 96.

A. LATERAL VIEW OF LARYNX OF DIDELPHIS OPOSSUM.

a, thyroid cartilage; *b*, cricoid; *c*, crico-thyroid ligament; *d*, trachea.

B. POSTERIOR VIEW OF THE SAME.

c, cricoid; *c*. laryngo-tracheal ligament; *d*, trachea.

FIG. 97.

LARYNX OF CAT.

a, tongue; *b*, epiglottis; *c*, superior vocal cords; *d*, inferior vocal cords.

In the kangaroo (*Macropus major*) several peculiarities occur in the larynx. In particular, the vocal cords are membranous, and fold upon themselves, so that they cannot be stretched by the arytenoids. The voice when in pain consists of a piteous moan. In the opossum (*Didelphis opossum*) the vocal ligaments are very short, hence the voice is acute. The opossum purrs like a cat.

In the order Carnivora we find examples of animals with intense voice.

In the lion (*Felis leo*) the larynx is well developed; the vocal ligaments, both superior and inferior, are present; the superior being prominent. The ventricles of the larynx are deep, forming a sac between the upper and under vocal ligaments. The windpipe is possessed of fifty cartilaginous rings. The voice is grave, highly intense, the roar terrific.

The tiger (*Felis tigris*) has a larynx resembling that of the lion, the superior vocal ligaments being very prominent. The voice of the tiger is more acute than that of the lion. It purrs like the cat. The leopard and the cat belong to the same genus. *Felis leopardus* and *Felis catus*. These two animals, like the rest of the feline tribe, have the superior vocal ligaments well developed. It is supposed that by these superior vocal ligaments the purring sound is produced. The voice of both animals is a mewing—they have by night a melancholy cry.

In the order Quadrumana, to which the apes and monkeys belong, the essential form of the organ of voice does not vary much, but

peculiarities occur in the resounding walls. Thus in the ourang-outang a sac exists between the thyroid cartilage and hyoid bone, and in the mandrill, pavian, and macacos, membranous sacs are observed below the hyoid bone. In the Myceti, or howling apes of the New World, the apparatus for the resonance of the voice is greatest. In these the hyoid bone and the thyroid cartilage are expanded in such a manner as to contain large cavities, which open into the ventricles of the larynx, and besides this there appear to be sacs common to the larynx and pharynx. Further, the epiglottis in these apes has a very large and peculiar form. In the Sapajous (Ateles and Cebus) a curved tube is formed by the increased size and altered forms of the epiglottis, and some adjacent structures. The voice of these animals has a whistling character.

Fig. 98

LATERAL VIEW OF LARYNX OF CHIMPANZEE. *aa*, sac connected with the lateral ventricle: *b*, hyoid bone, with *c*, sac protruding at its base; *d*, thyroid; *e*, trachea; *f*, cricoid.

In the chimpanzee the true vocal ligaments are prominent. The windpipe has sixteen rings. The voice is more acute than in women; its quality inferior, owing probably to the sacculated larynx. In the ourang-outang the inferior vocal ligaments are prominent, but not so long as in the families of the human race. The ventricles are valvular, so that the inflation of the peculiar sacs is under the control of the animal.

In the Gibbons the ventricles are deep, and communicate with a sac. The voice is acute; the cry "bow wow."

In the monkeys of the old continent there are also laryngeal sacs. These sacs modify the quality of the voice, giving to it, even when acute, a peculiar hoarseness. In the Simia appella and Simia capucina, there are some peculiarities in the structure of the channel for the passage of air. The voice in quality is like that of a flute; hence these are called whistling apes, and, from the peculiar expression of this whistle, which is a plaintive melody, they are termed weeping apes.

Voice of Birds.—The great peculiarity in the organs of voice among birds is the inferior larynx; that is, birds, in addition to the larynx corresponding to that possessed by mammals, have one peculiar to themselves at the inferior extremity of the windpipe. Even the superior larynx of birds differs considerably from the larynx in

mammals The superior larynx, like that of mammals, is placed just below the hyoid bone. It is partly cartilaginous and partly osseous. In the superior larynx of birds there are cartilages corresponding to the thyroid and the cricoid, the two arytenoid, and the epiglottis. The cricoid is much less developed than in mammals; it forms but a small portion of a ring, occupying the posterior part of the larynx, and supporting, as in mammals, the two arytenoid cartilages. The thyroid cartilage, consequently, rests on the first ring of the windpipe. To the posterior margins of the thyroid cartilage are connected two quadrilateral bones, by which the extent of the protection afforded by the wings of the thyriod cartilage is much increased. The arytenoid cartilages are long, and taper upwards and downwards; they form by their inner margins the chink of the glottis. They are generally ossified; their external margins are bounded by the thyroid cartilage. The epiglottis in most birds is rudimentary, and generally is osseous. The chink of the glottis in birds is triangular, the apex being directed upwards. It is bounded in front by the thyroid cartilage, on each side by the arytenoid cartilages, and behind by the cricoid cartilages; but it has no salient membranous laminæ, such as the vocal ligaments in man and mammals are. It is capable of expansión and contraction under the action of several muscles. The inferior larynx is, as we have seen, peculiar to birds. It varies very much in form and structure. This larynx, the vocal instrument of birds, is a tube, at the opening of which is a membranous tongue. This tongue is a doubling of the interior lining of the bronchus, its free margin being directed upwards; and birds have for the most part a smaller or greater number of muscles, capable of shortening this tongue or of lengthening it in the direction of its height, and of rendering it tense or lax in a transverse direction.

FIG. 99.

SECTION OF INFERIOR LARYNX OF BIRDS.

In general the inferior larynx of birds is produced by a membrane which makes a projection on each side of the inferior orifice of the windpipe; this orifice is divided into two apertures, sometimes by an osseous bar passing from before backwards, sometimes merely by the angle of union between the two bronchial divisions of the windpipe The bronchi are not composed, like the windpipe, of complete rings, but merely of osseous or cartilaginous segments of rings of a greater or smaller number of degrees in extent, each having a proper curvature in the state of rest, which curvature may vary to a certain amount by the action of voluntary muscles.

It hence follows, that the portions of the walls of the two bronchial divisions of the windpipe, adjacent to (that is, looking towards)

each other, are for a greater or smaller extent membranous, being there destitute of any osseous or cartilaginous structure; and it is to this usually large portion of the wall of each bronchus to which Cuvier gives the name tympaniform membrane. Thus two tympaniform membranes descend, looking towards each other from the angle at which the windpipe divides, forming the interior wall of each of its subdivisions, and being extended transversely between the anterior and posterior extremities of the upper osseous segments of these same subdivisions; these osseous segments extending only along the posterior, the external and anterior part of their wall, so as to leave the inner part of each bronchus simply of a membranous structure.

The first osseous segment of each bronchus has much the same curvature as the windpipe itself; but the second and third are portions of larger circles, and are less convex exteriorly than the first, so that these last project on the inner side of the tube.

On this interior projecting part the lining membrane forms a fold, and it is this fold, half shutting one of the inferior apertures of the windpipe, which offers to the air issuing forth a tongue capable of vibrating and of producing sound.

The inferior larynx of singing birds, and some other birds whose voice is far from musical, is very complicated. The last rings of the windpipe unite into a structure two or three lines in length, nearly cylindrical above, and expanded below, where it has two obtuse points, one anterior, another posterior, joined by the bony bar passing from before backwards, already spoken of more than once. This bar is so placed that the windpipe opens below by two oval holes, making with each other an obtuse angle, and each of these holes communicates with one of the bronchi.

The three first osseous segments of each bronchus are more near to each other and flatter than those which succeed them. From the first to the third there is a gradual elongation behind, so that the posterior extremity of the last makes a sort of projection, owing to the sudden diminution of the fourth segment. The arc which these segments form hardly exceeds 60°, and in each bronchus the chord of this arc, so to speak, is the tympaniform membrane. The first segment of each bronchus curves its anterior extremity towards the innersurface of the tube, where it articulates with a small oval cartilage which is fixed to the tympaniform membrane, while it forms within a prominence which is the vibrating lamina of the larynx on that side. Thus the transverse section of each bronchus is below nearly circular, the section higher up becomes the segment of a circle which diminishes in one direction while it enlarges in another; and the passage of the air upwards into the windpipe takes place by two oval holes, each furnished at its anterior border with a salient

lamina. This apparatus is supplied with ten muscles, five on each side.

Of these, one descends from the interior of the windpipe to the anterior extremity of the third segment of the bronchus, and, by its contraction, draws that point upwards, thereby making the vibrating lamina project farther inwards, and, at the same time, rendering tense lengthwise all that part of the tympaniform membrane lying below the segment to which the muscle is attached. Another muscle parallel to this has nearly the same attachments, and a like office. A third muscle, much smaller, extends from the inferior and posterior part of the windpipe, and is inserted into the posterior extremity of the second bronchial segment. Its action is similar to that of the former. A fourth muscle passes obliquely from the windpipe to the posterior extremity of the second bronchial segment. It draws that segment upwards and outwards, so as to aid the action of the muscles already referred to, and of that which follows. The fifth muscle is no longer than the preceding, but is much thicker. Taking its origin from the last ring of the windpipe, it passes downwards and forwards, and is inserted into the anterior extremity of the first bronchial segment, and particularly into the minute cartilage already mentioned as being articulated with that point. Its chief action is to draw forward the small cartilage, and consequently forcibly to put on the stretch, in a transverse direction, the upper part of the tympaniform membrane.

Such a complex structure of the inferior larynx belongs, as was hinted at, not only to singing birds—such as the nightingale, the wren, the blackbird, the goldfinch, the lark, the linnet, the canary, and chaffinch—and to those with a monotonous cry, like the swallow, the sparrow, the starling; but also to some with a decidedly disagreeable cry, such as the jay, the magpie, the crow, the raven. Thus not only is a complex organ necessary to the musical singing of birds, but also a fine general organization and a singing instinct.

The windpipe in birds presents some very singular modifications. As the voice is produced in the inferior larynx of birds, situated at the lower part of the windpipe, this tube comes to form, together with the mouth, the tube or pipe placed in front of the organ of voice. In short, the windpipe of birds comes to occupy a place corresponding to the situation of the organs of speech in the human body. It is capable of being shortened, not only by the diminution of the spaces between the rings themselves, but also by the rings being received one within the other. In many birds the windpipe is much longer than the neck, being thrown into convolutions. This structure is observed in the cock-of-the-wood, the stork, and crane. In the wild swan the convolutions of the windpipe are lodged in a cavity of the breast bone. Nor is the windpipe always cylindrical;

for in herons and cormorants it has a conical figure, becoming gradually wider and wider towards the mouth. In some species of ducks it presents a sudden dilatation, while in the goosander, and some members of the duck family, it undergoes gradual dilatations.

That the inferior larynx of birds is the true organ of voice has been proved by many experiments. For example, anatomists have divided the windpipe in singing birds, such as the blackbird, about the middle of its length, so that the air could no longer pass through the superior larynx, and yet the bird would continue to sing, though with feebler tones than before. Similar experiments have been made on magpies and on ducks. After such an experiment, the magpie is found to cry with as great intensity of tone and with the same acuteness as before the operation. Again, if air is blown into the bronchial divisions of a duck after their separation together with the inferior larynx from the body, a sound exactly similar to the natural cry of the bird is obtained. Even after the bronchi have been cut away, by blowing into the trachea the same sound is produced.

It is not, however, to be concluded that the superior larynx exerts no modifying influence on the voice in most birds. It is manifestly opened and closed rapidly in singing birds, so that it is impossible to doubt that it takes an active part in the production of melody. In the song of the canary and the linnet its simultaneous movements with those of the mouth are readily observed. Its effect, however, on the pitch of the voice is not supposed to exceed a semi-tone. Physiologists still doubt whether the sounds of the voice in birds are the result, as in man, of the vibrations of a reed or tongue, or, as in mere flute-pipes, of the vibrations of a column of air excited by friction against the lips of an opening. There is unquestionably a great difference in the mode in which voice is produced in different birds. It seems certain that the simple organ of voice in the duck, the goose, and the like, is a reed instrument. In these the vocal cords, or bands, which form the exterior margin of the opening of the larynx, can be seen to vibrate strongly, while the sound produced closely resembles that arising from the vibrations of membranes. But it is by no means so clear that the piping, whistling sounds of singing birds are produced in the same manner; and it is not impossible that these may be effected in the same mode as whistling by the mouth in man.

Several reasons, however, may be urged in favor of the opinion that the sounds uttered by singing birds are the effect of the vibrations of tongues, as well as the voice of the duck and the goose. For example, the vocal cords under muscular action can hardly escape being thrown into vibrations; and even though the friction of the air may be in part concerned in the production of the sounds,

a compensation must arise between the vibrations of the air and those of the vocal ligaments. If this be correct, the organ of voice in birds would not be entirely analogous to a whistle or pipe, but would in part possess the constitution of a reed instrument. It is found that the length of the windpipe has but a very slight influence on the note produced by the larynx; and that fact corresponds with the slight effect on the pitch of the notes produced by placing a tube in front of the human larynx. It is also found that sounds produced by blowing, by means of a tube inserted in a bronchus through the lower larynx of some birds after its separation from the windpipe, are not perceptibly altered in pitch by holding a tube in front of the larynx: thus is confirmed the resemblance of the lower larynx in birds to the character of the larynx in man. It may be added, that the greater number of the notes of birds may be obtained from the inferior larynx by varying the force of the blast, which at first sight seems to point to a resemblance with the effect of blowing by varying force upon the notes of flute-pipes of the same size as the windpipe of small singing birds. But it is to be remembered that the same variations of notes, by varying the strength of the blast, may be produced in reed instruments with membranous tongues, and even in reeds with very delicate metallic tongues.

The influence of the windpipe on the notes may be either the same as that of the notes of flute-pipes, or it may merely influence the notes in the manner of the tube of reed instruments. Contraction of the upper opening of the windpipe at the superior larynx may lower the note, as in pipes and reed instruments.

An influence may be exerted on the sounds produced in the lower larynx by the tympaniform membrane, which vibrates strongly at the time. Between the internal vocal cord; the semi-lunar membrane, and the tympaniform membrane, there is a relation of compensation, the latter being analogous to the membrane formed of a reed stalk.

The muscles which vary the tension of the walls of the vocal pipe are in continued action during the modulation of the voice, in order to adjust the tube of the windpipe to the pitch of the glottis; but the number of vibrations may be determined by the glottis, reinforced by the walls of the pipe, as in mammals.

The voice of birds, as of other animals, is also in a minor key. The range of notes is commonly within an octave, though some birds can greatly exceed it. In the parrots, which have a voice of great power, the inferior larynx is single. The two membranes of the larynx leave a narrow chink between them, through which the air is forced from the lungs. These membranes, vibrating in all their dimensions, produce that harsh and disagreeable quality of sound peculiar to them. They can also whistle, during which the

glottis is probably silent, and the column of air vibrates as in a flute, when a vibratory movement is communicated by the air traversing the elastic walls of the tube. Besides the power of speech possessed by some birds, many can imitate almost every sound they hear; the blackbird has been known to imitate the sound of the nightingale, the crowing of the common cock, and the cackle of the hen. The jay is said to mock the notes of the greenfinch and the neighing of the horse so closely that it was scarcely believed to be a bird by those who heard it; also the calling of fowls to their food, and the barking of the house-dog.

The variety in the song of singing birds is a subject of the greatest interest. The songsters, properly so called, include the skylark, the woodlark, the thrush, the blackbird, and the nightingale. A slight notice of the notes of each of these follows:

The skylark is one of our most agreeable songsters. Its song is composed of several strains, each consisting of trilling and warbling notes variously modulated, occasionally interrupted by a powerful whistling. Sometimes the lark sings on the ground, perched on a clod, or crouched among the grass; but generally in commencing its song it starts off, rises perpendicularly or obliquely in the air, with a fluttering motion, and continues it till it has attained its highest elevation, which not unfrequently is such as to render the bird scarcely perceptible. Even then, as remarked by a distinguished naturalist, if the weather be calm, you hear its warble coming faintly on the air at intervals. The lark is also a bird of singular capacity; the young learn the notes of any other bird which hangs near them in confinement, and some full-grown birds are observed to possess a like facility. There is, however, a considerable difference among larks in the strength and melodiousness of the note. In confinement some larks begin to sing as early as November, and go on singing until moulting time; others begin in March, and cease as early as August. In the wild state their period of singing is much shortened.

The woodlark is considerably less than the skylark, but of all the larks it is the sweetest songster. Its voice has all the melody of the flute, marked at times by a tender and even somewhat melancholy strain. It sings sometimes in the air, sometimes on the top of a tree. When singing in the air it is frequently seen flying in large, irregular circles. The woodlark sings late in the evening, so as sometimes to be mistaken for the nightingale. The female woodlark, like the female of larks in general, is not destitute of song; but all that it can reach is a few strophes much interrupted.

The thrush has a clear and beautiful song. On the tops of the highest trees it welcomes the approach of spring, and sings throughout the whole summer, especially in the morning dawn and the eve-

ning twilight. It is kept in a cage by bird-fanciers, whence often on a morning, even as early as February, it will delight a whole street by its pleasing song, outside the window, or even inside, provided the window be a little open. The thrush in its wild state is fond of bathing. In September and October they are often caught at the places where they water, before sunrise and after sunset, and even so late that they cannot be seen, but only heard. At the time of bathing they have a peculiar call-note. When a thrush finds water, or when it is flying towards a known watering place, it pipes loudly *sik, sik, sik, sik, siki, tsak, tsak!* and immediately all the thrushes in the neighbourhood reply, and come on.

The blackbird has a song rich in melody, containing some deep notes, like those of the nightingale, yet varied with some which are unpleasantly harsh. When at liberty it sings from March to July, particularly at night. In the cage it sings throughout the whole year, except at moulting time. Its note is pure, distinct, and clear. It has a good memory, and will learn several airs or melodies without confusing them. It is even able to imitate words.

The nightingale by the fineness of its voice surpasses every other bird. The variety and peculiarity of its tones express its varying emotions. When the male is alone, its most significant note is the pipe-note *witt*. But if the harsh syllable, *krr*, be added, it forms the call of the male to the female. To express anger or fear the note *witt* is repeated with great loudness and rapidity before the termination *krr* is added. When happy and contented the nightingale utters a deep *tack*. Under the excitement of anger, jealousy, or alarm, the nightingale utters an unpleasant shrieking tone, which resembles the cry of the jay. When they sport and chase each other, which they frequently do in pairing time, they utter a very short chirping sound. Such notes belong to both sexes; but the power and the brilliancy of his song distinguishes the male. His vocal organ is of striking power; the muscles of his throat are more robust than those of any other singing bird. Besides the strength of his voice, the nightingale is remarkable for the force, the agreeable transitions, and the beautiful harmony of his song. Commencing softly, he warbles for a moment a succession of low melancholy notes, which gradually increase in strength, and at last die away upon the ear. A variety of sharp notes follows, and then are uttered numerous hurried sharp notes, intermingled with some detached ascending notes, with which he generally closes his strain. In the song of a fine nightingale, without reference to slighter variations, there are at least four-and-twenty different strains.

Among the sparrow and finch tribes there are many much prized singing birds.

The bullfinch has naturally a harsh, creaking tone, but young

birds learn all kinds of songs, airs, and melodies. If it be desired that a bullfinch should sing perfectly, it ought never to be taught more than one melody, in addition to the fanfare, which is always added by way of surplus.

The chaffinch has a variety of notes expressive of its wants and desires. There is one delicate note, expressed *treef, treef*, by which it appears to remark a change of temperature. The call-note, which it uses chiefly on its migration, is a repeated *yack, yack*. A spontaneous sound appears to be *fink, fink*, which it reiterates, and from which perhaps the root of its name is derived. More remarkable than these notes is its clear and trilling song; as approaching more to distinct articulation, it is termed a quaver. Each bird has one, two, three, and often as many as four different songs, each of which lasts a couple of seconds, and consists of several strophes. Those who desire a particular account of the different songs of the chaffinch, may consult "Chamber Birds," by Bechstein, translated from the German by Mr. Shuckard, London, 1848.

The linnet has a very remarkable, loud, and flute-like song, consisting of many connected strophes, which is the more beautiful the oftener it utters some high-sounding notes, which are termed its crowing, from the resemblance to the crowing of a cock. From its natural flute-like voice, this bird surpasses all others in its capacity for imitating melodies in a beautiful and pure style. A young linnet taught by a nightingale has an exceedingly pleasing song.

The goldfinch has a shrill, agreeable song, heard during all seasons, except at the period of moulting. It contains many warbling and twittering notes, on which it dwells more or less, and the oftener the syllable *fink* is repeated the more it is admired. Some birds utter these notes only once or twice in their song, while others give them forth four or five times in succession. The goldfinch does not acquire the song of other birds with so much ease as the linnet and the canary.

The canary is distinguished by correctness of ear, by the remarkable skill it possesses of imitating all tones, and by an excellent memory. While canaries imitate the notes of other birds, they mix them with their own, so as greatly to improve the song. In different countries canaries exhibit a different character of melody. Those birds which intermix in their melodies several strophes of the song of the nightingale, are called Tyrolese canaries. The English canaries, on the contrary, imitate the song of the lark.

Even birds of prey often exhibit no small extent of voice. The kestrel has a bell-like ringing voice, *kli, kli, kli*, which he often repeats in rapid succession. The white owl utters a plaintive cry, which by the superstitious has been regarded as a sign of death. The raven has a hoarse croak resembling the syllable *crock* or *cruck*,

but it also utters a note not unlike the sound of a sudden gulp, or the syllable *cluck*, which it seems to utter when in a sportive mood. The rooks have a considerable variety of sounds. Their chief cry resembles the syllable *khraa*, more or less harsh or soft according to occasion. There is great diversity in the voice of individuals, the notes of some being much louder and clearer than those of others. Their cries, separately, are monotonous and disagreeable; yet when at some distance, and uttered by a large flock, they become by no means unpleasant. Mr. M'Gillivray describes the sounds proceeding from a rookery at night as consisting of a variety of soft, clear, modulated notes, very unlike their usual cry. He regarded these sounds as expressive of affection, and was persuaded that the mothers were fondling and coaxing the newly-hatched young.

The jackdaw is extremely clamorous, with a loud and clear note, resembling the syllable *kae* or *caw*, variously modulated. The noise produced by a large flock, though in no degree musical, is far from being disagreeable. The jay can even learn to speak, uttering, however, nothing but solitary words. They may be taught also the fanfare of a trumpet, and other melodies of single bars, as well as little airs and the notes of many birds. The magpie imitates all striking sounds, and can be taught to speak more easily than any other of the crow tribe. The cry of the cuckoo is universally welcome as the harbinger of spring. His principal sound is nothing but *hu-hu* or *coo-coo*, repeated at short intervals; when attention is given, however, it is found that these two loud and mellow notes are preceded by a kind of churring or chuckling sound, which consists of a low and guttural inflexion of the voice, during which the throat seems distended.

The parrot tribe are most remarkable for their power of imitating human speech. The cockatoo shrieks its own name, *cockatoo*, and calls loudly, in a trumpet-like tone, *derdeny*. The cries of all animals it acquires, particularly those of the domestic cock and hen. It rarely, however, acquires the power of articulating words. There are numerous species of cockatoo parrots having much the same character of voice. Among the commonest of the parrot tribe in Europe is the ash-coloured parrot. This parrot readily learns to speak, and to pipe. It has not the unpleasant wild shriek of some of the parrot tribe. It takes no small delight in imitating the voice of children; hence children are its best instructors. If its education be begun early, it will sometimes acquire entire verses, and even axioms.

The gray woodpecker has a note which resembles a loud shout of laughter, whence some of its popular names are derived; this note is never varied, except by its more clamorous repetition during the spring and early summer months, and by the peculiar cry, *plui, plui*,

plui, which has been supposed to indicate the approach of rain. The wryneck in spring frequently and loudly utters *gigigigi*, which is the call whereby he attracts his mate. The nuthatch utters a loud call, which may be heard at a considerable distance, resembling *grew, deck, deck*. The ring-dove, or cushat, has a loud and particularly pleasing cooing, during which he makes very grotesque motions, which may be backwards and forwards, or from side to side, moving the head in every direction. The turtle-dove has a peculiar cry, and bows his head while it is uttered.

Voice of Reptiles. — The sounds uttered by reptiles and amphibious animals have their source in the larynx, like the voice of mammals. In frogs, as well as in the crocodile, there are vocal cords. In the crocodile the larynx, though more simple than in mammals, still retains something of the same character. There is one large, long-shaped cartilage, to which are attached two movable cartilages. The mucous membrane descending from these movable cartilages into a deep pouch beneath, leaves a free fold on each side, which, when the movable cartilages approximate, becomes a vocal cord. In the gecko and the chameleon the vocal cords are more developed than in the crocodile; nevertheless they are formed on the same plan. The lizard has an acute, chirping voice, which has been supposed to depend on a peculiar membranous fold attached to the larynx, but it really seems to depend on a vibration of the margins of the glottis. In the turtle tribe there are no vocal cords, nor is their larynx adapted to a perfect intonation of the breath.

In the true serpents there are no vocal cords; the hissing sound which constitutes their imperfect voice is a mere forcible breathing. In the male frog membranous sacs at the side of the neck become distended in the utterance of the voice, and serve to increase its intensity. In the *Rana pipa*, in which the larynx, as in all other frogs, receives the bronchi directly, without the intervention of a windpipe, there is a large cartilaginous box, within which are two solid reed-like bodies, nearly as long as the larynx itself. The anterior extremities of these bodies are fixed; their posterior extremity is free, and projects on each side towards the opening of the bronchus. The vocal sound is produced by the vibrations of reed-shaped tongues, which act like a tuning-fork; while in other animals of the same class the parts which produce the sound are membranous. If a small piece of cartilage, a few lines in length, be fixed by one end, and a

FIG. 100.

RANA TEMPORARIA (COMMON FROG)—*Bishop*.
a, tongue; *b*, hyoid bone; *c*, superior vocal cords; *d*, inferior vocal cords; *e*, pharynx; *f*, right bronchus.

current of air be thrown from a small tube upon its edge at the other extremity, a humming sound is heard. In the *Rana pipa*, also, the movable cartilages are convex externally, and concave internally; so that when the entrance to the larynx is closed, they form a dome over the windpipe, which has been compared to a kettle-drum. In the *Rana temporaria*, *R. esculenta* and *R. hyla*, the larynx opens into two sacs on either side of the lower jaw, and these, during the cry of the animal, are filled with air.

Sounds produced by Fishes. — A very few fishes are known to utter sounds, such as the trigla, cottus, pogonias.

The trigla utters a grunting sound when it is taken out of the water. It has been supposed that the peculiar muscle of the air-bladder in these animals has a share in causing the sound. The cottus, however, from which a sound is heard to proceed when pressure is made upon its body, has no air-bladder. The pogonias, on account of the sounds which it produces, has been named the tambour. These fishes produce continued sounds under the water. The air-bladder is very large, and is covered by strong muscles; further, it has appendages, which, according to Cuvier, pass between the ribs, and become embedded in the muscles.

Sounds produced by Insects. — Most insects are mute; others produce sounds merely by friction; others, again, by the passage of air through their spiracles. The sounds produced by friction come under the head of stridulation; those produced by air from the spiracles, purring or humming. In the orthoptera, and some of the coleoptera, there are parts adapted to produce stridulation.

In the cricket the muscular apparatus may be described as consisting of a serrated string like a file, which in the movement of the wings is drawn rapidly over a firm, transparent, and nearly triangular disc, or sounding-plate, surrounded by a string, and by this act the sound is produced. The pitch of the sound of the house-cricket is very acute, being equivalent to about 4096 vibrations in a second.

The cicadæ, termed sometimes the "*chanteuses*," or singers, are so called because the males produce, in the hottest part of the day, a kind of monotonous and noisy music:—

"Et cantu querulæ rumpent arbusta cicadæ."—VIRGIL.

The music of the grasshopper has from early times attracted attention. Archias sung of it, and his verse has been thus translated from the Greek:—

"Erst on the fir's green blooming branch, O grasshopper! 'twas thine
To sit—or on the shady spray of the dusky, tufted pine;
And from thy hollow, well-winged sides to sound the blythesome strain,
Sweeter than music of the lyre to the simple shepherd's swain."

Those, too, who loved these "living lyres in the olive groves sounding all the summer long," have celebrated the locust:—

> "Soother of loves, encourager of sleep,
> O locust! mystic muse, shrill wing'd;"—

And the cicada,

> "Cicada! thou, who, tipsy with the dews
> Of weeping skies, on the tall poplar tree
> Perch'd swayingly, thyself dost still amuse,
> And the hush'd grove, with thy sweet minstrelsy."

Melanger, alluding to the buzzing of insects, says, "Excute facundas pedibus titubantibus alas:"—

> "Striking thine own speaking wings with thy feet;"

but their real organs of sound are placed on the side of the base of the abdomen, internal, and covered by a cartilaginous plate, like a shutter, which is an appendage of the under side of the metathorax or posterior thorax. The cavity which incloses these instruments is divided into two partitions by a scaly and triangular edge. Seen from the under side of the body, each cell exhibits anteriorly a white and folded membrane, and in the hollow part an extended, slender membrane, called the mirror. If this part of the body be opened from above on each side, there is seen another folded membrane, which is moved by a very powerful muscle, composed of a great number of straight and parallel fibres, extending from the scaly ridge; this membrane is called the *timbale.* The muscles, by contracting and relaxing with quickness, act upon the *timbales,* stretching them out or bring-

Fig. 101.

THORACIC SPIRACLE OF BLUE-BOTTLE FLY (*Musca vomitoria*).

Fig. 102.

THORACIC SPIRACLE OF HUMBLE BEE (*Bombus terrestris*).

ing them into their natural state, whereby the sounds are produced, and which, even after the death of the animal, may be repeated by moving the parts over each other in the manner they act whilst alive. The cicadæ occur chiefly in warmer countries of the world. One species, the *Cicada Anglica*, the only English species, is found in the New Forest.

It is a common belief that the buzzing of insects is produced by the oscillations of their wings during flight. This idea has been often called in question. John Hunter found that insects emitted sounds after their wings were cut off. More recently it has been stated that the sounds produced by many insects are the effect of a rapid transmission of air through the thoracic air-holes as they dash through space. Mr. Bishop has observed a peculiar mechanism for this purpose in the blue-bottle fly and humble bee. The preceding figures show one of the large thoracic spiracles in each of these insects, the *Musca vomitoria* and the *Bombus terrestris.*

The Application of Physiology.—After the foregoing details of the chief points in the economy of living nature, it will not, in conclusion, be inappropriate to exhibit some of the great truths of Physiology; to trace their connection with other subjects of human inquiry; and to point out some of the uses to which a knowledge of this department of science is practically applicable.

Physiology, taken in its largest acceptation, holds a most prominent place in the circle of human knowledge. We have seen it trace the development of the perfect man through the grass of the fields back to the common mineral elements of the crust of the earth. It also enlists in its service Anatomy, Chemistry, and not a few departments of general Physics; and it connects itself with Agriculture, Political Economy, and the science of Legislation and Government, hardly less than with Medicine, Surgery, and the preservation of health.

The most striking truth in physiology is, that organic existences, including alike the highest races of mankind and the meanest vegetable organisms, are, in their material composition, derived from the mineral matter of the earth. The properties of the simple elementary substances entering into the vegetable and the animal kingdom have been ascertained with exactness; in their mineral condition, they have been fully investigated; and their chemical properties and combinations in inorganic nature are well understood. And such knowledge leads to a second great principle in physiology—namely, that there is nothing in the properties of these several elements of the organic world by which any tendency is given to them, beyond the rest of mineral matter, to combine together to produce any form of organic life, however simple, and however transitory. When, then, in connection with this undeniable truth, it is considered that,

for long periods of time, our planet, the earth, must have been, from physical circumstances, totally incapable of supporting any form of organic existence, the conclusion follows, that the appearance of organic existences on the earth implies an exercise of Infinite Power, by which mineral matter was endowed with the new property of passing into the first species of animal and vegetable life. It is vain to say that such statements as these lie without the pale of inductive science. Man's natural curiosity loudly asks whence came organic species, whenever he considers the undeniable truth that the surface of the earth must have lain for ages destitute of such existences; and the answer which, by the original constitution of his mind, he is compelled to give, is, that such a change on the mere matter of the crust of the earth, as its transition into living forms, could not have occurred without the interposition of Omnipotent Power.

This great truth, then, is not the less a natural inference of the human faculties, because it does not strictly fall within the limits of physiology; it owes its origin to the operation of the great principles of human belief, implanted in the mind by its primitive constitution, and on the knowledge supplied by the cultivation of physiology. The next great step in the progress of man's knowledge of organic nature lies strikingly within the limits of physiological science. It is the conclusion that each organic species had its origin in a separate creative power. It is vain for any one pretending to the character of a philosopher to maintain that the idea of a transmutation of species is far more simple and far more in accordance with Infinite Wisdom. Every one endowed with a philosophic spirit must at once reject this idea, simply because there is not a shadow of foundation in its behalf to be met with in the whole of nature. It is impossible to pronounce with certainty, from physiological evidence, whether the several races of plants and animals at present living, or discovered by geological evidence to have formerly existed, had their origin from one pair, or from many pairs; but the strongest evidence does exist against the supposition that one species of a lower grade can pass successively into other species of a higher grade. On the contrary, nature has guarded each species from change with the most sedulous care. By artificial means, and within certain limits, man can make various changes in the species, both of plants and animals; and accidental circumstances, without man's interference, produce like variations. But it is fully ascertained that, as soon as those circumstances, whether designed or accidental, which have caused a variation, have ceased to operate, then the species returns to its original state.

As soon as physiology, by drawing upon the philosophy of mind, has overcome the difficulty attendant on the first appearance of organic nature on the surface of the earth, it traces out by observation all that belongs to the economy of organic existence. By such

observations physiology has made known the conditions necessary for the development and maintenance of organic existences as well as for their reproduction; and as far as physiology has yet discovered, so long as these conditions can be maintained in respect to each species, no tendency is shown to its becoming extinct. At the same time, a question may arise whether organic species have the power of unlimited existence, as species, so long as the ordinary known conditions necessary for the maintenance of the individuals continue unimpaired, or whether a species be, like the individual, capable only of a limited existence; so that, as in the case of the individuals of which it is composed, its prolific life at last begins to fail. The experience of mankind on the earth is probably not yet sufficiently extended to afford any sufficient data for debating this question. But the striking analogies between individual life and the life of a species in other respects, must prevent us from positively affirming that species can only die by a failure in the ordinary conditions under which the individuals of that species are seen at present to live and thrive. In the case of the individuals of every species, no matter how abundantly the conditions of their life are supplied, there comes at last a period when their susceptibility of availing themselves of those conditions declines, so that decay and death are the inevitable consequences. In the species of plants and animals best known to physiologists, no tendency has ever yet been remarked to degenerate, except that which owed its origin to a failure in the conditions necessary for the existence of the individuals of that species. The dodo is an example of a species which has become extinct within the records of history; but a single case hardly affords a sufficient ground even for conjecture; and it is, perhaps, right at present for physiologists to content themselves with the belief that the dodo perished from fortuitous causes interfering with the external conditions necessary to enable the individuals of that species to live and thrive on the earth's surface.

Here, however, in stating the great truths of physiology, the importance of the law of death in the organic world, as taking that part of nature entirely out of the category in which mineral nature exists, must not be omitted. In physiological nature, then, the law of death may be thus stated—no perfection of organism, no completeness in the supply of the conditions of existence, can prevent any living individual whatever from at last failing to derive the means of maintenance from those conditions, and from falling into a state of decay and dissolution. Such a law is exclusively known in physiological nature, there being nothing the least analogous to it in the case of inert matter.

A more practical truth of physiology is, that each species multiplies in proportion as the circumstances under which it is placed are favourable to the maintenance of the individuals of that species.

This law appears to admit of no exception. In short, physiological principles are quite sufficient to settle the questions which have arisen as respects the law of population. No country can support more inhabitants than it can supply with the means of maintenance. It is not necessary that the soil of that country should produce enough of corn and cattle to feed all its inhabitants; but then it must produce something else by means of which food can be obtained from other countries. If the inhabitants are skilful workmen, they may convert raw material, derived from other countries, into manufactured goods; and for the value of their workmanship they may receive enough of corn and cattle to satisfy their wants. There may be mines of mineral wealth in demand among agricultural nations; and in exchange for this wealth they may obtain a sufficiency of corn and cattle. Still the great law remains unaffected that the number of people which a country can maintain cannot exceed that for which it possesses the means of providing food.

Physiology enters upon another practical question of vast importance — namely, whether the soil of a country can be renewed independently of the application of existing organic matter. Every crop which is taken off a field carries with it a certain amount of soil; not, indeed, equal to its actual weight, because a great part of the substance of each crop is derived from the air, and from the rains. Hence a soil necessarily becomes exhausted by repeated crops. It is renewed by the application of manure; but as manure, in common circumstances, is obtained from organic matter, it is plain that the organic matter of a country must be continually declining by being again reduced to mineral matter; unless it be proved that under some circumstances, at least, soil can be renewed from the mineral kingdom. The annual waste of organic matter in every country is enormous—that is to say, a large quantity of organic matter is continually passing back into the mineral state, under such processes as putrefaction, combustion, and the respiration of animals. Plants, no doubt, are continually converting inorganic matter, such as the carbon of carbonic acid and the hydrogen of water, into their own substance. But the organic substances required for food contain not only hydrogen and carbon, but also nitrogen; and therefore, unless it be proved that ammonia, which is the chief source of the nitrogen of plants, be constantly produced in the mineral kingdom, it must be confessed that there is a continued irreparable destruction of organic matter upon the earth's surface. Here there is a controversy among chemical authorities—some contending that ammonia is continually formed in the mineral kingdom; others that the ammonia which appears in a soil is derived solely from the decomposition of organic matter. On the determination of this question our speculations rest as to the future history of the organic kingdoms on the surface of our planet. If there be a continual destruction of organic

matter without any corresponding renewal from the mineral kingdom, then a time will come when plants and animals must perish for want of the means of subsistence at present supplied to them by the soil. It is no part of our purpose to enter upon this controversy; but the evidence at present seems to be in favour of the unlimited power of mineral nature to produce ammonia, and therefore to supply that important constituent of the food of plants which otherwise must be derived from the destruction of organic matter.

Another speculative question bearing on the fortunes of the animal kingdom is sometimes debated in works of physiology. We have already remarked, that the carbonic acid, which is continually thrown into the atmosphere by the respiration of animals, is as constantly decomposed and removed by plants for their own support. It is a common view that our atmosphere must, at a very early period, have contained all the carbon, in the form of carbonic acid, which now exists in the organic kingdoms, and in the soil of the earth. If such were the case, the atmosphere, however fit to support the life of vegetable organisms, must, it is said, have been totally unfit to maintain the life of animals. The supposition then is, that through the vast preponderance of the vegetable kingdom, for many ages, on the surface of the earth, the carbonic acid was gradually reduced in proportion down to its present small measure; and that the carbon so abstracted from the carbonic acid is that which now forms so large a proportion of the bodies both of plants and animals, and so large a proportion of the soil of the earth. And now that the animal kingdom has begun to preponderate, and a greater proportion of carbonic acid is produced by the respiration of animals than is decomposed by the food of plants, this change will go on increasing, until at last the atmosphere will become again unfit for the support of animals, owing to the great accumulation of carbonic acid. The determination of this question involves several considerations. It is true that the forests which covered the earth in ancient times are fast disappearing; but it is also true that these forests are replaced by cultivated crops. Shall we then say that if all the arable parts of the earth become covered with crops, those crops will not destroy as much carbonic acid as the ancient forests? And if this be the case, then the carbonic acid will not undergo any material increase. One thing is certain, that the animal kingdom, as respects its constituent carbon, can only increase at the expense of the vegetable kingdom; so that, while there must remain the same quantity of carbon at the earth's surface, a larger proportion will certainly be contained in the animal kingdom than in the vegetable, owing to the destruction of the ancient forests. But if the whole quantity of carbon contained jointly in the crops, and in the animal kingdom, and in the soil, remains equivalent to the quantity now in those three conditions, no change can take place in the quan-

tity of the carbonic acid in the atmosphere. Again, it is perhaps impossible that the animal kingdom can increase so fast as to deteriorate the air much, when it is considered, that the only part of the animal kingdom that can be regarded as on the increase, is man himself, and the animals subservient to him.

An easy answer to the difficulty which has been here raised is, that by computation, from very probable data ("Edinburgh New Philosophical Journal," July, 1845), the conversion of the whole carbon of the soil, and of living plants and animals, into carbonic acid, would not more than double the small proportion of that gas existing at present in the atmosphere.

The connection of pestilential diseases with deficiency of the means of subsistence has too little engaged the attention of legislators. It is true there are certain diseases of an epidemic character, such as small-pox, measles, scarlet fever, which prevail even among the best fed orders of society. It is undeniable, however, that even these epidemics are far more fatal when joined with an insufficiency of food. In modern times, it is hardly possible to conceive the ravages which, in the earlier ages, epidemics inflicted upon the human race. At those periods, agriculture had made but very slender progress; and what surprises us is not so much that the nations of Europe suffered from such diseases as that they did not suffer even more. Were the same circumstances which so often prevailed in those countries again renewed in the present crowded state of many of the countries of Europe, the devastation would be far greater than even we find to be recorded of those times. Great sanitary improvements have taken place in all the countries of Europe, defective as that kind of legislation still is. But when the rapid increase of our great towns, without any previous means being secured for their proper drainage and ventilation is considered, physiology cannot too loudly proclaim, not only that virulent epidemic diseases may arise under such circumstances, but extend their ravages even beyond the limits of those localities in which imperfect regulations prevail.

As respects the general maintenance of health, physiology supplies many important precepts; although nature in this respect has hardly left man to be governed by physiology. Hunger forces man to the highest activity for the preservation of his life; and under this appetite, aided by common sense, a body of popular dietetic rules has arisen, the habitual observation of which, more from imitation than from reflection, serves to preserve individuals in health. It is only by seeking a variety of food that man is sure to obtain all the chemical constituents required for the maintenance of his bodily frame. We have already shown that each of the simple elements, of which the human body is composed, is continually passing out by various excretory channels; and that, unless replaced, nutrition

becomes deficient, and the function of that part which fails to receive its just supply is necessarily impaired. It doubtless often happens that the digestive powers are too feeble to extract the substances required from one kind of food, while they may be sufficient to obtain them from another. The desire of a variety of food, then, is plainly a species of instinct implanted in man for the purpose of securing the perfect nutrition of the animal frame.

Physiology is the handmaid of medicine; and in its largest sense, it even includes pathology. The relation between physiology proper and pathology has no parallel in other departments of knowledge. In physical science, as there is no death, so there is no disease. The mere derangement of machinery invented by man is very different from the state of disease in physiological nature. But not to waste time on a subject scarcely relevant to our present purpose, it is at least manifest that in the derangement of machines there is not, as in the case of disease, a power inherent in them to rectify and to restore themselves to their former state of efficiency. Such a power, however, is what characterizes pathology in particular. It is sometimes said that in meteorology, storms and tempests, as contrasted with calm weather, are the diseases of the atmosphere. But even in this department there is no close analogy between the two cases. A mere disturbance of the equilibrium of the atmosphere, on which every sudden change of the weather depends, bears but a very remote analogy to the pathological states to which living nature, and in particular the human nature, is subject. But when we come to chemical science — to that science which treats of the combinations of bodies, and of their actions and reactions upon each other, then we perceive at once how totally different physical nature (and under chemistry the whole of physical nature falls) is from organic nature, in respect to that class of phenomena which constitute the special department of physiology termed pathology. In chemical nature there is no individuality, unless, rejecting the idea of the infinite divisibility of matter, we pronounce each atom of a chemical substance to possess an individuality. And this view at present supplies us with the best and most correct notion of the grand distinctions existing between physical and physiological nature. The individuals, then, of which chemistry treats are mere atoms of simple bodies — every massive simple body is merely a group of individual atoms — each of these atoms is, in a very definite sense, an independent individual; it possesses all the properties which belong to the mass or aggregate in which it is seen to exist; by being separated from that mass it loses nothing; in the present system of things it is imperishable; it knows no decay, it knows no fatigue, it knows no exhaustion of its properties, it knows no dissolution or death. From its first creation to the time when the Eternal shall pronounce the fiat of its extinction, it knows no change of character.

How different are the terms in which the individual falling under physiological nature must be spoken of! Here the individuality lies in the peculiar aggregation of a great mass of different particles; no two individuals are exactly alike; no individual is exactly like itself even for a moment; there is a perpetual change; even the very atoms which compose the individual are continually disappearing—the form remains, while the substance is continually changing; there is an unceasing rise, progress, decay, and dissolution; the dissolution, however, does not lie in the loss of the constituent substance, but in the failure of the indispensable form. Here, then, lies the great distinction between the individuals of physiological nature and the individuals of physical nature. In physical nature each individual retains throughout all time its proper identity; is always the same under the same circumstances; associates itself in innumerable ways with other individuals like itself, but never loses its own peculiar properties and character. The individual of physiological nature retains its identity through the best part of a century, while the substance which renders it a sensitive body is continually undergoing a change. It retains no identity of mere matter, but only an identity of form and spirit. An atom of carbon now exists in the crayon of the artist; now floats about the atmosphere from pole to pole in a new combination; now enters into the constitution of some vegetable nature; now is a component part of some animal frame; now is cast forth again into the atmosphere, and thus enjoys an immortality of existence altogether free from the laws of accident, disease, or death.

Physiology is the truest guide in medicine; and man is by nature a physician — is an observer of diseases, and of the means under which, whether by design or accident, diseases have disappeared. Medicine in its ruder states exhibits a few individuals who have not only been themselves diligent observers of diseases and remedies, but also inquirers into the experience of others. There are certain parts of medicine and surgery open to common observation without much risk of deception or error. But as long as a man is ignorant of physiology he is groping in the dark; he is deceived at every step; he mistakes mere successive occurrences for events standing in the relation of cause and effect; and, if he be of a rash character, or even only of an ardent mind, he is very apt by his interference to aggravate rather than promote the cure of disease. When physiology has made some progress — that is to say, when the spirit in which the Creator willed the actions of living nature to take place has been apprehended—then men begin to discriminate the shades of disease with more accuracy, and to observe with less risk of error what remedies have contributed to a cure. Till physiology made such progress, medicine was overburdened with precepts rashly inferred by unskilful observers.

The last great use of the science of physiology to which we shall advert, is its intimate connection with that science which points out the evidence of design in nature; and it is in the organic world chiefly that we find such evidences.

It is a great error to suppose that human knowledge is confined to determining the laws according to which phenomena occur. Those who study the evidence of design in the universe, are sometimes reproached with deviating from the proper purpose of philosophy. They are told that philosophy has nothing to do with the origin of things; but only with the laws which regulate the phenomena which man is capable of observing. But this is an assumption purely gratuitous. It is quite true that man in early ages made small progress, attempting to find out the purpose for which everything that exists was made. It is also true that Bacon described final causes as barren of effect. But if we find that the knowledge of nature, and particularly of organic nature, has now advanced so far that the study of the purposes for which organic parts were made, leads to the elucidation of the science; and that the study of final causes is no longer that barren pursuit which it was in Bacon's time; then we are entitled to repel this reproach, and to consider on what grounds it is affirmed that man's knowledge must be confined within the investigation of the mere laws of phenomena, and not extend to the study of the purposes to which the various forms of organic structure are subservient. There is manifestly no other ground for affirming that human inquiry should be confined to the study of the laws according to which phenomena take place, than the argument that this is the only way in which human knowledge can be extended. Those who so argue altogether ignore physiology. The most ancient expression for physiology is the *usus partium*, that is to say, the use of the parts of the body. What does this mean? Surely it signifies that the study of the parts of the animal frame and of the vegetable structure, leads to a knowledge of the design with which the animal or the plant was made after that fashion. The discovery of the use of a part is not only a new step in physiology, but the observation of the relation between the structure of a part and its function is a fact in evidencing design. Till that discovery is made the human mind remains altogether unsatisfied with the most minute knowledge of the mere structure. The extent to which this is true will at once appear from the species of shame with which anatomists and physiologists point out those organs in the animal frame, the distinct use of which has not yet been discovered. There are such organs in the body, for example the spleen, the thyroid gland over the upper part of the windpipe, the supra-renal capsules, and some parts in the anatomy of the embryo. The most persevering efforts are continually made to connect *the structure* of such parts with some definite use in the living body.

What are these efforts but the most conclusive confession that the human mind cannot rest satisfied with the mere knowledge of the size, the form, the minute internal structure of a part, unless it be able to conceive with what purpose that part was placed in the situation which it occupies?

The character of human knowledge is not to be sought in the speculations of philosophers. A far truer standard of the character of human knowledge will be obtained from the common principles which pervade the minds of mankind at large. It is vain to attempt to extinguish man's curiosity to know why a part was so constructed, or why it was placed in the situation which it occupies. Such inquiries are as natural to him as the desire to discover the laws which regulate the succession of phenomena. It is not to be supposed, however, that man has been gifted with powers sufficient to discover the whole plan on which organic nature is constructed. He need not expect to become able to explain the particular purpose of every variety of structure which he discovers in the animal and vegetable kingdom. It is long since physiology reached the truth that, in some species, there are parts of structure which do not seem to have any special office; or any special bearing on peculiar habits. It is long since physiology became acquainted with what are termed rudimentary structures, both in the imperfect and in the mature state of individuals. The simplest example of a rudimentary organ is the mamma in the male of the human race. It performs no office. The disciple of a positive philosophy points to those organs, and sneeringly asks how this is to be reconciled with our doctrines. But, suppose all the rudimentary organs which are known, and all the peculiarities of structure in animals, which seem to serve no useful purpose in relation to the habits of the animal, were deducted, what an infinitesimal proportion would the total amount of these make as compared with the vast array of organs with distinct uses, left to constitute the evidence of design! The disciple of a positive philosophy sarcastically asks, of what use it is to the whale to have the bones corresponding to each of the bones in the human arm, or upper extremity? Here we answer by referring him to his favourite term, LAW: it is a law that the great orders of animals are developed upon one grand type. This law we discover by observation; it is a part of inductive science; it has nothing to do with design. But, having ascertained this law of development according to the type, we then discover that the type is made to bend into a conformity with the particular habits and usages of each species.

Here, then, is a great fact; and notwithstanding the law, in obedience to which the unwieldly whale, with its short fin-like arms, has in those arms a bone corresponding to every one of those in the human upper extremity, yet are these analogies of the human bones so modified as in the most perfect manner to become subservient to

the different uses to which this animal applies its anterior extremity. The disciple of the positive philosophy no doubt says—surely the fore-paw of a whale might have been constructed on a more simple plan, to answer all the uses to which it is subservient. But does this answer shake the foundations of the evidences of design? Before his arguments become of any avail, he must show that the fore-paw of the whale is unfit for the purposes required by the habits of that animal, because it is framed on the type of the human upper extremity. We do not pretend to say why it has pleased the AUTHOR OF NATURE to establish that law according to which the skeleton of mammals conforms to a certain type; but we do affirm that the AUTHOR OF NATURE, having restricted His creative power within the limits of that type, has displayed incontrovertible evidence of design in adapting the type of the human arm to the form of the fore-paw of the whale, in conformity with the uses which that part has to perform.

Such, then, is the kind of difficulty which presents itself in our reasonings upon design. The physiologist should never forget that his subject falls under the laws of inductive science, in as far as these are applicable to it; and he should never permit the disciple of a positive philosophy to refuse him the alternative of so regarding it, or considering the discovery of the fitness of means to an end as a new step in its progress.

A very remarkable feature in physiological nature is, that, after all, each individual, though composed of materials derived from mineral nature, is not dependent for his individuality and identity on the continued presence of that same aggregate of mineral substances. At every moment the materials of which a human being is composed are passing away, and giving place to new materials derived from without. In a short period of time, the substance of his body is entirely changed, yet his individuality, his identity, his personality remain. He is the same, and yet different. He is no longer the same matter; but he is the same man. The man is therefore something different from matter. Let the disciple of the positive philosophy expound this to us; If everything be material—if all the phenomena of the organic world be the result of internal laws belonging to material substances, what is it that represents man throughout his long life, notwithstanding the perpetual change of the matter which at any one moment composed his bodily frame? Man surely is something different from matter; he is a thinking spirit, and one of the earliest of his thoughts is to refer the changes which he sees taking place around him to Infinite Power, and to recognise in the accommodation of means to ends, the inherent design of Infinite Intelligence.

Truly did Galen say—"The study of physiology is a hymn in honour of the Deity."

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